Tests of a Jacobs-Shupert Boiler

W. F. M. GOSS

TESTS

of a

JACOBS-SHUPERT BOILER

in comparison with a

RADIAL-STAY BOILER

A Report submitted to

Mr. A. F. HUSTON

President of the Jacobs-Shupert United States Firebox Company
Coatesville, Pennsylvania

by

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I. Letter of Transmittal

MR. A. F. HUSTON,

President, JACOBS-SHUPERT *United States Firebox Company,*
Coatesville, Pennsylvania.

DEAR SIR:

In obedience to your direction, transmitted under date of August 24, 1911, I have approved the designs and superintended the construction of two locomotive boilers identical in their general dimensions and differing from each other only in the fact that one was fitted with a Jacobs-Shupert firebox and the other with a radial-stay firebox. I have since subjected these boilers to an elaborate series of tests. I transmit herewith a report of the methods employed, of the results obtained, and of the conclusions reached.

Respectfully submitted,
W. F. M. GOSS.

CHAMPAIGN-URBANA, ILLINOIS,
July 31, 1912.

II. Introduction

1. The Jacobs-Shupert United States Firebox Company, in undertaking the manufacture and sale of a new type of steam boiler, early determined to conduct an elaborate series of tests as a preliminary step in the development of its business. There had already been numerous tests designed to disclose the behavior of various details entering into the construction of the boiler, and there were already one hundred and sixty-nine locomotives having Jacobs-Shupert boilers in successful operation. In addition to these significant facts, the Company desired for its own information and for the information of boiler users in every field of service, to make of record a correct and comprehensive statement of the merits of the new type of boiler. A tentative program of tests was drawn up and its execution was intrusted to the undersigned, who as expert in charge was given a free hand in the working out of the details. It is the purpose of this report to present a full statement of the work done and of the results obtained.

2. For the purpose of gaining some understanding of the behavior of the Jacobs-Shupert boiler in service, a trip of inspection was made to a number of roundhouses and shops where locomotives equipped with such boilers were being handled. An account of this inspection is set forth in Chapter VI of this report.

3. In cooperation with Mr. Charles Ducas, the able Technical Manager of the Jacobs-Shupert United States Firebox Company, the elaborate series of tests which has now been concluded, was planned. The tests have involved the construction of two modern locomotive boilers, differing from each other only in the fact that one was fitted with a Jacobs-Shupert firebox and the other with a radial-stay firebox. Both boilers were built to the general dimensions of a certain standard of the Atchison, Topeka & Santa Fe Railroad. The firebox employed in the construction of the Jacobs-Shupert boiler was not especially made for the test, but by permission of the Santa Fe was taken at random from a number of similar fireboxes under construction for that Company. No radial-stay firebox for a boiler of the dimensions selected was available, and as a consequence one was especially constructed, its overall dimensions being made to agree accurately with those of the Jacobs-Shupert firebox. Each boiler, as first constructed, was partitioned off into two compartments by an extension of the back tube-sheet in all directions to the outside shell of the boiler. The tests made when the boilers were thus equipped permitted a separate determination of the heat transmitted by the firebox heating-surface and by the tube heating-surface (Chapter VIII). The performance of the boilers thus equipped was determined when oil and coal respectively was used as fuel. This work having been completed, the partitions were removed and the boilers subjected to such reconstruction

as was necessary to make them normal to conditions of service. Tests were then made to establish the performance of the two normal boilers (Chapter IX). This accomplished, each boiler was subjected to a test of strength under low-water conditions with results which are set forth in Chapter XI.

4. While one important purpose of the several chapters which follow is to discuss and summarize the results obtained, a most interesting and promising field of study is supplied by the unembellished numerical data derived from the tests. These are presented complete, with a full description of the methods employed in obtaining them, as Chapter XIII. Not only does this chapter contain the commonly presented facts concerning the performance of the two boilers tested, but it also presents for most of the tests the results of a complete heat-balance. By reference to the tables of this chapter, therefore, the student of steam engineering will find material for comparisons involving many factors which do not appear in the more descriptive chapters preceding.

5. It will interest those who have occasion to follow this work to know that it is stated by the officers of the Jacobs-Shupert United States Firebox Company that the entire capital for its business has been supplied by the Lukens Iron & Steel Company. It has been remarked as of more than ordinary significance that this Company, having so much at stake, and understanding perfectly that adverse results might have meant the closing up of a business, should have fearlessly acquiesced in the plans of the Firebox Company, whereby a single expert was authorized to undertake the comparative tests and was given a free hand in carrying them out.

6. In the execution of its program of tests, the Jacobs-Shupert United States Firebox Company is indebted for substantial assistance to many different agencies. Chief among these is the Lukens Iron & Steel Company upon whose premises all the work was done. The organization of men and the equipment of this magnificent establishment being at all times available, greatly facilitated the progress of the work. Whatever the need, whether for rough labor, for skilled labor, or for materials, it was always supplied practically on demand. The interest in the tests which was manifested by Messrs. A. F. and C. L. Huston, President and Vice-President, respectively, both of the Lukens Iron & Steel Company and of the Jacobs-Shupert United States Firebox Company, permitted no desire of the expert in charge to go unsatisfied.

7. The United States Bureau of Mines, in recognition of the significance of the tests, has cooperated in the work so far as circumstances would permit.

8. The undersigned finds pleasure also in acknowledging his personal indebtedness to Mr. P. C. Haldeman, Master Mechanic of the Lukens Iron & Steel Company, to Mr. A. M. Baird, Master Boiler Maker, and to his personal assistant, Mr. J. F. Butler. W. F. M. G.

Champaign-Urbana, Illinois,
July 31, 1912.

III. A Brief Story of the Development of the Locomotive Boiler

9. The boiler is the locomotive's primary source of power. However efficient the details of its engine, they can be effective in the development of power only when furnished with an ample supply of steam. This must come from the boiler. The boilers of early locomotives were small and inefficient and the problem of improving them as it has presented itself to succeeding generations of designers has been beset with difficulties.

10. An early form of locomotive boiler was a plain cylindrical structure containing a single flue. At one end of this flue a fire-door was attached, and inside the fire-door, grate bars were arranged. At the other end an elbow was added to connect with a vertical stack. By this arrangement the stack was in front of the boiler, not on it. When the locomotive was operating, the elbow and a considerable portion of the stack were commonly red-hot. An improvement consisted in fitting the boiler with a return flue which brought the stack and fire-door at the same end, and which provided more heating-surface, a longer flameway and lower stack temperatures than were possible with the earlier design. The famous "Puffing Billy," a locomotive which did effective service for many years, was provided with a boiler thus constructed. Obviously, the power developed by such an arrangement could not be great, and the commercial success of the locomotive awaited the advent of a boiler having greater capacity. This came when George and Robert Stephenson designed and constructed the multitubular boiler for their famous locomotive "Rocket." This boiler had a plain cylindrical shell fitted with twenty-five 3-inch copper tubes extending from end to end of the boiler. At the front-end a smoke-box was attached which discharged into the stack. At the back-end a box-like fixture was added to constitute the firebox. The superior success of the "Rocket" over that of previously existing locomotives was due largely to the fact that its boiler gave an abundant supply of steam.

11. The "Rocket's" boiler fixed the general lines to be followed in the building of locomotive boilers for many succeeding years, but it did not completely solve the problem of the firebox construction. That detail was destined to take on many forms in pioneer days, and it is one which has been the subject of much debate and change in more modern times. The first tubular boiler having a self-contained submerged firebox, seems to have been that of the locomotive "Planet" built by the Stephensons for service on the Liverpool and Manchester Railway in 1830. The firebox was rectangular in plan. While the Stephensons subsequently devoted

themselves to the development of this form of construction, others built fireboxes which were circular in plan, crowned by a hemispherical dome, a form well chosen to resist the stresses imposed by the internal pressure of the boiler. In the process of developing such structures, however, practice came gradually to rely for strength less upon form and more upon stays by the use of which a structure weak in form could be held in place. A firebox rectangular in plan being desirable, other forms gave way to this plan. The stability of the sides and ends of all such fireboxes was secured by the use of stay-bolts connecting the inside and outside sheet. The support of the crown-sheet proved a more difficult matter. For many years it was provided for by the application of crown-bars running over the crown-sheet either longitudinally or transversely, the latter being the more common arrangement in this country. The crown-bars were metal girders of such form as to permit them to extend across and above the crown-sheet while receiving their support from feet bearing on the upper edges of the side-sheets. A series of such crown-bars served as lines of support for the crown-sheet which was held up by suitable rivets or bolts. The crown thus supported was in effect carried by the side-sheets, and while this type of construction proved serviceable for many years and is still used in small boilers, the time came when in the development of the American boiler it had to give way to something better. As the dimensions of fireboxes increased, the crown-bars became enormously heavy, and the load which they imposed upon the side-sheets became so great as to complicate the problem of firebox maintenance. In this emergency a part of the load was for a time removed from the side-sheet by carrying heavy sling stays from the crown-bars to the outside shell of the boiler, but the relief thus obtained was only partial, and the size of boilers continued to increase. For a time and to a very limited extent in this country, the crown-bar boiler was followed by the Belpaire boiler, a design in which all portions of the firebox are stayed, and in which the outside of the boiler is so formed as to permit all stays to connect sheets which are parallel. But the real successor of the crown-bar boiler has been the radial-stay boiler, in which the crown of the firebox is curved to a form which will permit its being held up by stays extending to the outside shell or wrapper sheet. The lines of the stays extended do not necessarily radiate from any single point, but their arrangement suggests such a possibility; hence the term "radial stays." As compared with the Belpaire, the radial-stay type presents greater difficulty to be overcome in making an analysis of the stresses which are set up in its several parts by the presence of internal pressure, but it is lighter and probably on the whole equally satisfactory. The radial-stay firebox of the present day may have either one of two forms. It may be "wide," in which case the side-sheets extend in a straight line from the mud-ring to the curved portion of the crown-sheet, or it may be "narrow," in which case the side-sheets extend vertically for a short distance above the mud-ring, then

curve outward and finally back again to meet the curvature of the crown-sheet. In either case, stay-bolts closely spaced connect the side-sheet with the outside sheet of the boiler.

12. Practice has developed many embellishments in the construction of this form of firebox. First, it has found that longitudinal stresses imposed upon the tube-sheet make it desirable to have a certain element of flexibility locally about the tube-sheet, and hence instead of inserting rigid radial stays at this point, two or more rows of sling stays are used. The design of these is such that while giving adequate support to the crown-sheet they offer no resistance to the movement referred to. A second embellishment is to be found in the use of button heads on the firebox end of some or all radial stays. The design of these heads is such as to provide a broad bearing for the plate upon the head of the stay, a connection which is altogether stronger than is obtained by merely screwing in the straight stay and heading it. Practice has also developed certain forms of flexible stays for use in the water-leg and higher up in the boiler. These devices are such as to permit some change in the angular position of the stay without imposing transverse stresses upon it at points near the outside sheet. These and many other embellishments in its design have permitted the radial-stay boiler to perform a service which as measured in power output per unit weight is superior to that of any type previously employed in locomotive service, and it is this fact which chiefly has resulted in the wide use of the type. But the necessity for certain of these embellishments and the practical difficulties which are experienced in maintaining the modern radial-stay boiler suggest deficiencies in the fundamental principles underlying its design and the time will doubtless come when the large sized radial-stay boiler will entirely give way to something that is scientifically more sound. The promise of such a consummation is to be seen in the recently developed Jacobs-Shupert boiler which was first put in service in 1909. This type of boiler has in the past three years been subjected to extensive use and to elaborate laboratory tests, with results which as to maintenance cost and strength are entirely complimentary to the new design.

13. The Jacobs-Shupert boiler in its external form follows the general lines of the radial-stay boiler, of which it is to be regarded as a logical development. It differs radically from its predecessor in the structural characteristics of its firebox and in the means employed for supporting it. The Jacobs-Shupert firebox provides an element of longitudinal flexibility which the firebox of the radial-stay boiler does not possess, and thereby eliminates strains due to expansion which must be met by the rigid sheet of the radial-stay boiler. It makes no use of stays in side-sheets or crown, and hence abolishes completely a fruitful source of trouble which is always present in the radial-stay type of boiler. The support of the side-sheets and crown is secured by means of rivets submerged in the water-space of the boiler, no one of which can be exposed to the direct heat of the

furnace. As a consequence, the strength of the Jacobs-Shupert boiler under low-water conditions as compared with that of the radial-stay boiler is vastly augmented. A fuller description of this latest type of locomotive boiler is presented as Chapter V, and an account of its performance constitutes the subject of Chapters VIII to XIV, inclusive.

IV. The Modern Radial-Stay Boiler

14. The radial-stay boiler has constituted an important factor in the development of the modern high-powered American locomotive. For a score of years the locomotive designer has endeavored to secure larger boilers. In working out this purpose, the machinery of the locomotive has been lightened, steel has been substituted for cast-iron, and to insure the exclusion of unnecessary weight, the design of every detail of mechanism has been subject to the closest scrutiny. All that has been gained through the better design of machine parts has been utilized by giving increased weight to the boiler, but here again no unnecessary material has been allowed. In the design of the boiler, the effort has been to secure maximum heating surface for minimum weight. It is in the development of this general conception that the radial-stay boiler has been brought to its present-day standard. It has given the American locomotive greater steaming capacity and power than have been possessed by the locomotives of any other country. Whatever may be the future of the steam locomotive, the history of the art will not fail to give an important place to the radial-stay boiler.

15. However great the success of the modern radial-stay boiler, it must be admitted that under present-day conditions involving high steam-pressures and large firebox areas, it is a structure which is exceedingly susceptible to deteriorating influences. The difficulties appear chiefly in the firebox which as usually constructed is made up of five plates of steel; namely, two side-sheets, the tube-sheet, the door-sheet, and the crown-sheet. The side-sheets are usually flat plates of steel which are in the neighborhood of five feet wide and which may be nine or ten feet in length. As these plates must transmit heat from the furnace to the water of the boiler, they can not be heavy and they are usually three-eighths of an inch thick. Under modern conditions of operation, however, they must be so supported that they will resist a pressure of 14 or 15 tons per square foot. This is accomplished by the introduction of stay-bolts which tie the side-sheet to the outside sheet of the boiler. The construction is well shown by Fig. 1, which is a view of the water-leg of a firebox from which the barrel and throat-sheet have been removed. Obviously, there is no provision in the design of such a side-sheet for taking care of local expansion, and as a consequence the effect of such expansion can only find expression in bringing about a change of stress within the sheet itself. The result is that different portions of the side-sheet behave in different ways. They change their position with reference to the outside sheet of the boiler, causing stay-bolts to loosen, to become leaky, and in the zone of greatest movement, finally to break. This fact was recently emphasized by Mr. F. A. Delano,

President and Receiver of the Wabash Railroad, a high authority in railway mechanical matters, who in the course of a recent address,* said:

"A modern locomotive boiler has from 1,200 to 1,500 stay-bolts, between 4 and 5 in. apart, on all sides of the firebox. Under the law, five broken stay-bolts are sufficient to condemn an engine. This means that a locomotive boiler must be more than 99 per cent. perfect to meet approval; and yet it is safe to say that no high-pressure boiler can be cooled down and reheated again (as it must be for each washing out) without breaking at least this number of stay-bolts."

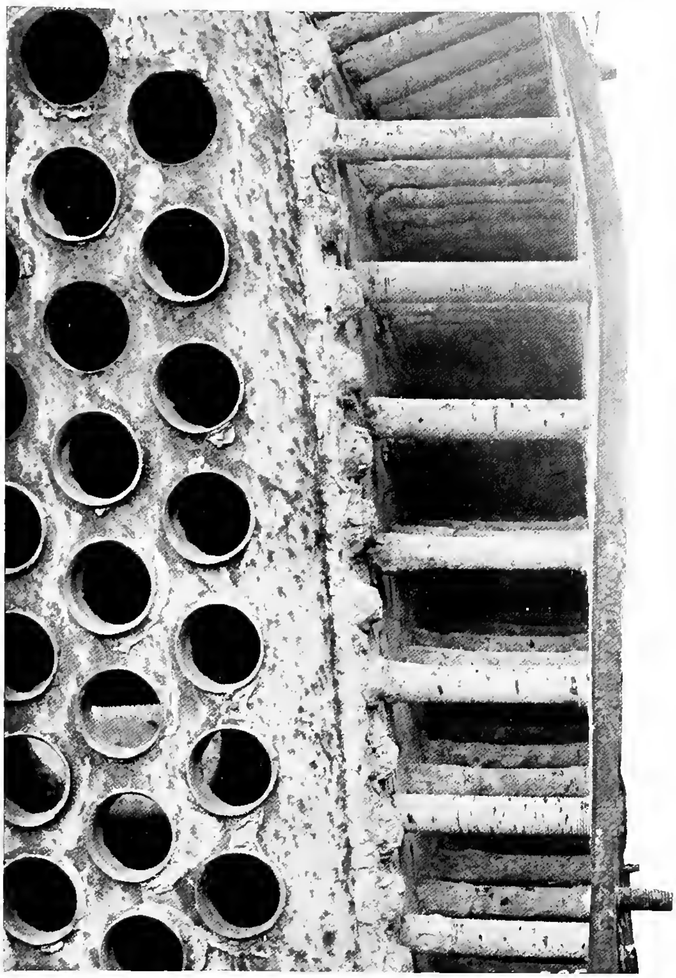

FIG. 1.—Firebox showing a heavy deposit of scale at the junction of the stay-bolts and firebox sheets, and the corrosion of the stay-bolts. Scale formation is also shown around the flue ferrules. These conditions are similar to those found in most locomotive boilers working under average water conditions.

Not only does trouble arise from the presence of stay-bolts, but the sheets themselves gradually bulge between the stay-bolts, and under unfavorable conditions of service they deteriorate rapidly. Fig. 2 shows a patch which in the process of making repairs has been applied to a bulged side-sheet. The appearance of the patch itself and especially of the patch bolts which hold it in place, suggests the difficulties that must be met in maintaining any flat sheet under the conditions of service to which a side-sheet is exposed.

16. The crown-sheet in the radial-stay type of boiler is usually curved. It must be thin, and in common with the side-sheets it must stand up under a pressure of approximately 15 tons per square foot, or a total load for a modern crown-sheet of 1,000 tons or more. Support is given the crown-sheet by the radial stays which tie it to the outside shell of the

*An address given before the Commercial Association of the State of Michigan, Detroit, April 17, 1912.

boiler, and which having considerable length permit some freedom of movement in the sheet under them. Consequently, the crown-sheet is more durable than the side-sheets, but it nevertheless suffers deterioration as an indirect cause from expansion and contraction stresses. Fig. 3 shows a crown taken from service, in which the plate is more or less bulged between stays, and in which the dark spots indicate pitting or local corrosion of the plate. Fig. 4 is a view into the water-space over the crown-sheet of a boiler from which the barrel has been removed. It indicates the size and the spacing of the stays. Four front rows were sling-stays, and these had been removed prior to taking the pictures. Figs. 5 and 6 show a similar view of a boiler with all the stays still in position. The illustrations well show the obstructions which are presented to the free movement of water over the crown-sheet, and the ease with which sediment or scale may collect upon certain portions thereof in this type of boiler. Fig. 7 shows a bulged and leaky crown-sheet from the fire-side.

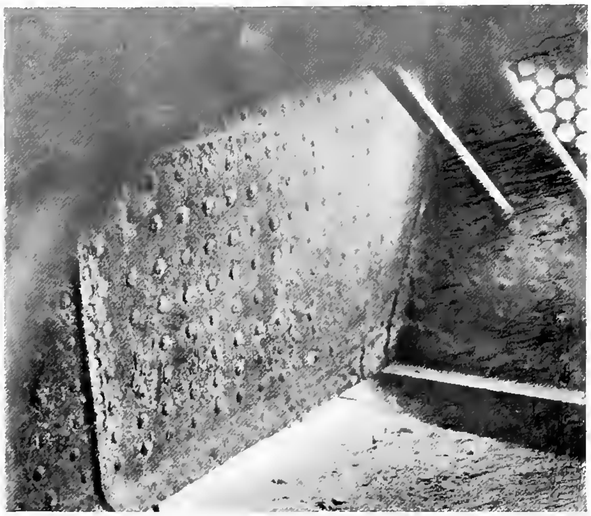

Fig. 2.—Patch on side of firebox showing the wear on such patches. The patch is, in general, in good condition, but the bolts at the rear end have started working down, and there are indications of cracks near the calking edge.

17. The back tube-sheet is one difficult to maintain in the radial-stay boiler. If its tubes leak they must be rolled, and the gradual process of rolling extends the tube-sheet upward with the result that the forward end of the crown-sheet gradually becomes bent upward and the fillet of the tube-sheet itself not infrequently expands above the level of the crown-sheet. Fig. 6 shows this rise in the fillet of the tube-sheet. One result of this extension is a gradual degeneration of the upper portion of the tube-sheet itself. Thus in Fig. 5 is to be seen a series of irregular cracks extending all around the top not far from the

Fig. 3.—Crown-sheet showing pitting and corrosion resulting from scale accumulation. This box was removed on account of this pitting.

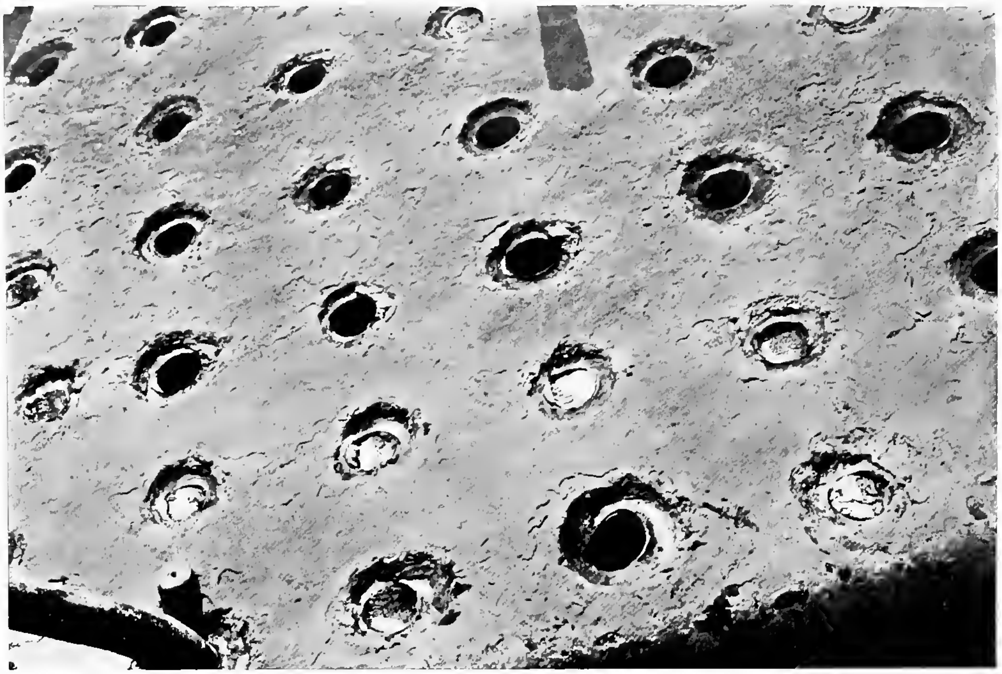

FIG. 4.—Crown-sheet showing the corrosion at the points where the bolts pass through it. This box was removed on account of the corrosion of the crown-sheet.

FIG. 5.—Water side of back flue-sheet showing cracks in the flange caused by the crimping action, resulting from the vertical movement of the sheet. This firebox was removed because of the pitting of the crown-sheet around the radial stays and crown-bar bolts.

point of its connection with the crown-sheet. Figs. 8, 9, and 10 show the degeneration of the tube-sheet resulting from stresses induced by the distortions already referred to. These illustrations are in nowise peculiar, but on the contrary, may be taken as entirely typical of the difficulties to be met in the maintenance of all large radial-stay fireboxes.

18. The forces at work within the structure of the radial-stay firebox, which ultimately bring about its ruin, are, under service conditions, always present, but the careless handling of the locomotive or the necessity for using a muddy, foaming or scale-producing water hastens its deterioration. Careless handling may expose the firebox to sudden changes of temperature which may result in leaks; the use of muddy or scale-producing waters may result in the deposit of solids on the sheets and lead to local overheating; and the use of foaming waters may operate in various ways to deprive the plates of the protection against overheating which they are designed to have. In other words, where the conditions are all favorable to longevity, the radial-stay boiler must be tenderly handled, and under conditions which are normal through large sections of our country, it is kept in service only as a result of constant attention. The radial-stay boiler is everywhere expensive to maintain, and its need of attention requires the locomotives to spend much time in the roundhouse, which might otherwise be given in service at the head of a train. It is customary on most roads to have a boiler maker go over the boilers after each trip, and on many roads the conditions are such that he must always do some work on them. Now a boiler that must be fixed after each brief period of service is to be compared with a highway bridge which must be mended after each passing vehicle—it serves an immediate purpose, but it leaves much to be wished for.

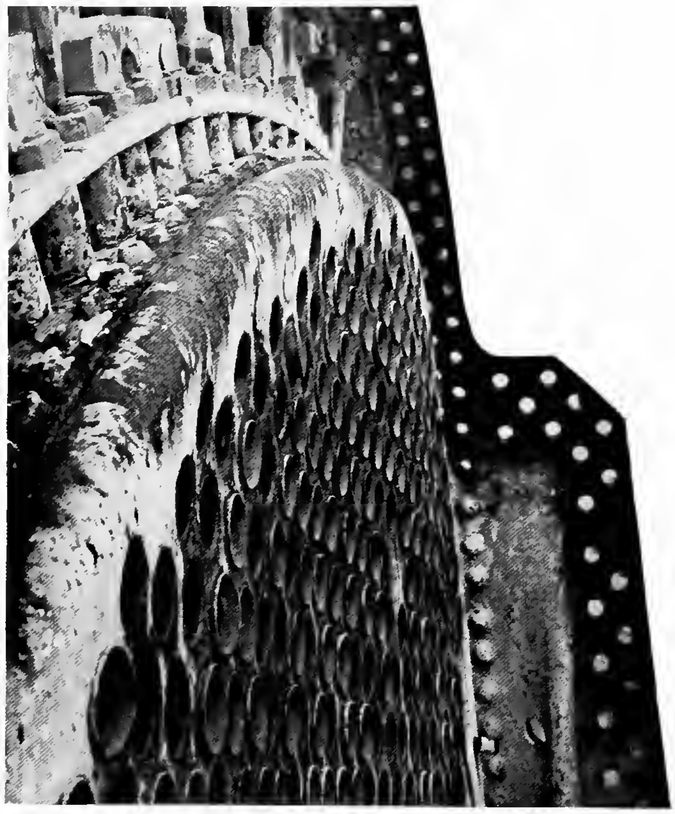

Fig. 6.—Back flue-sheet showing the deteriorated condition of its flange, which has resulted from the continually recurring strains.

19. Finally, the radial-stay boiler is weak, as have been all its prede-

cessors, under low-water conditions, and when failure occurs, the results are likely to be disastrous. A study of the radial-stay construction will suffice to reveal the explanation. The support of the crown-sheet is such that any local yielding imposes additional stress upon adjacent parts, and as these fail, the affected zone is extended, the process proceeding with such rapidity that the pent-up water and steam in the boiler is released with explosive effect. This is well illustrated by Fig. 11, which shows almost the whole crown to have come down together with a considerable portion of one side-sheet. The explosive effect of such a failure is apparent. A Committee of the American Railway Master Mechanics' Association, reporting at the convention of the Association in 1910, gives

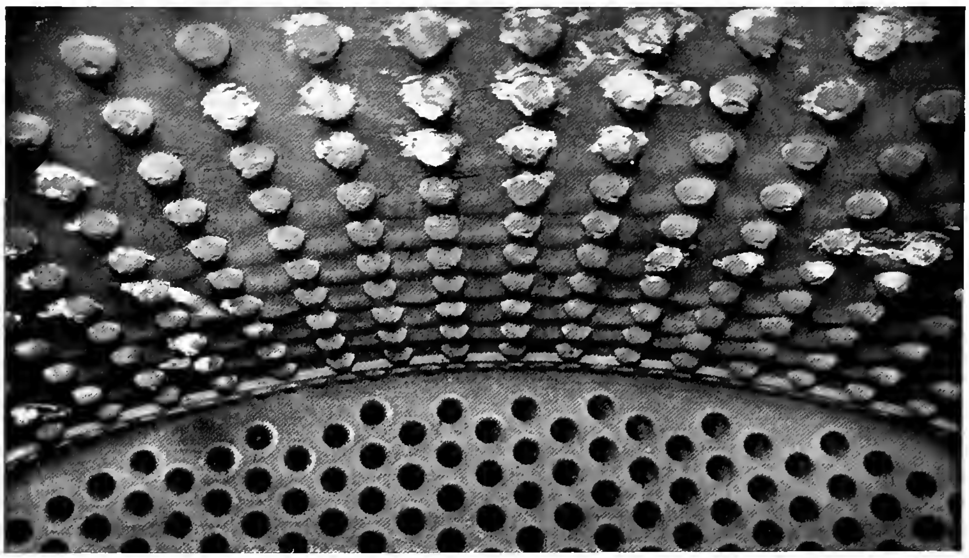

Fig. 7.—Photograph showing the bulging of crown-sheet between stay-bolts.

results of an inquiry concerning the number of boiler explosions, failures, and casualties to employees and others. The report was based on responses received from 157 railroads owning and operating 43,787 locomotives. The committee reports that during the period from June 1, 1905, to November 1, 1909, there were 246 firebox explosions resulting in the loss of 127 lives, and 2,499 fireboxes damaged by overheating, resulting in 142 deaths. More than 98 per cent. of these failures are said to have been due to low water. This statement makes it evident that low-water conditions are matters to be reckoned with, and that a boiler which is inherently weak when the water is low is at a disadvantage as compared with one which is less affected by overheating.

20. The explosion of locomotive No. 2538 which occurred four miles south of Yoncalla, Oregon, on April 4, 1912, may be accepted as typical of recent disasters. The accident in question occurred on the Oregon & California Railroad which is operated by the Southern Pacific Company. A report of the accident as formulated by the chief inspector of locomotive

Fig. 8.—Top of flue-sheet showing the badly deteriorated top flange.

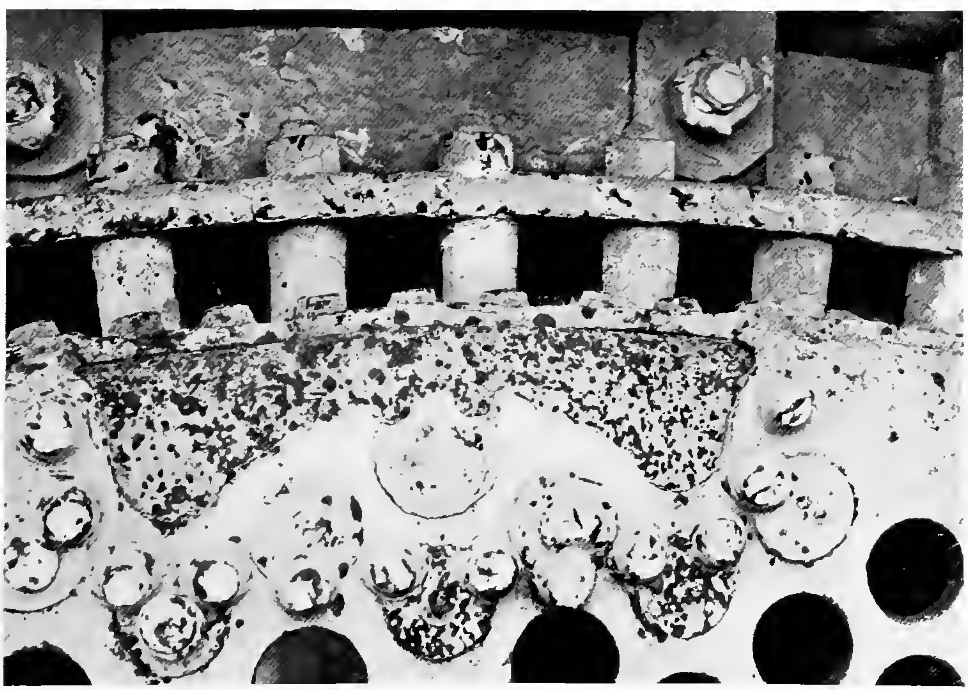

Fig. 9.—Top of flue-sheet showing patch. This patch was made necessary by the crimping action of the flue-sheet described in connection with photographs previously shown.

boilers of the Interstate Commerce Commission presents the following facts:

> The locomotive was of the consolidation type and at the time that it exploded was engaged in helper service on a south-bound train of 40 cars weighing altogether 1,605 tons. Three freight engines were coupled to the train, the road engine No. 3203 at the head and two others No. 2538 and No. 2194 between the caboose and the train. It was the boiler of 2538 that failed. The exploding boiler was blown clear off the frames of the locomotive, breaking or pulling out the expansion plates attached to the firebox, shearing cylinder saddle-bolts and breaking the saddle. It passed over three box-cars, apparently lighting on an oil-tank car, from which it rolled off to the right side and landed on the bank of an 8-foot cut at a distance of approximately 218 feet from the point where the explosion occurred. The engineer and fireman were both killed. The report continues: "At the time of the accident, the train was ascending a grade of 84.48 feet per mile at a speed of 10 to 12 miles per hour. The accident occurred on a tangent 627 feet south of a left-hand 8° curve. The elevation of the right-hand rail of this curve was from 3½ to 3¾ inches for a distance of 198 feet in the center of the curve. Our inspection disclosed the fact that almost the entire crown-sheet, with the exception of a portion of the left back corner, was overheated. The overheated portions of the sheet extended 4 inches below the highest part of the crown-sheet at the right front corner and one inch below at the left front corner. At the right back corner it was about on a line with the crown-sheet, while there had apparently been water on the left back corner. So far as could be ascertained by our inspection, the injectors, safety-valves and steam-gauge were in good condition."

The report concludes with the opinion that the accident in question was the result of overheating the crown-sheet due to low water. With the efforts of the inspector to fix the responsibility for the low water, the undersigned is at present not concerned, but he wishes especially to call attention to the fact that the crown-sheet came down as soon as any considerable portion of it was bare and before it was entirely uncovered. The modern firebox has so little power of resistance in the presence of low water that the fact that any part of the crown-sheet is bare is commonly accepted as a cause sufficient to explain a firebox failure.

21. It is obvious that any boiler, however satisfactory when properly handled, which possesses such enormous power of destruction when carelessly or imperfectly managed, always presents a certain element of danger. In stationary practice, progress in the art has produced certain types of boilers which in case of failure do not act with an explosive effect. In these so-called "safety boilers," the heating surface is subdivided so that a failure, if one occurs, is limited to a comparatively small detail; a break down can not easily become progressive. A failure is merely a blow-out. There is no explosion, and no damage is done beyond that of the affected part. There is no wreckage, and there are ordinarily no casualties. In this respect the design of the stationary boiler occupies a much

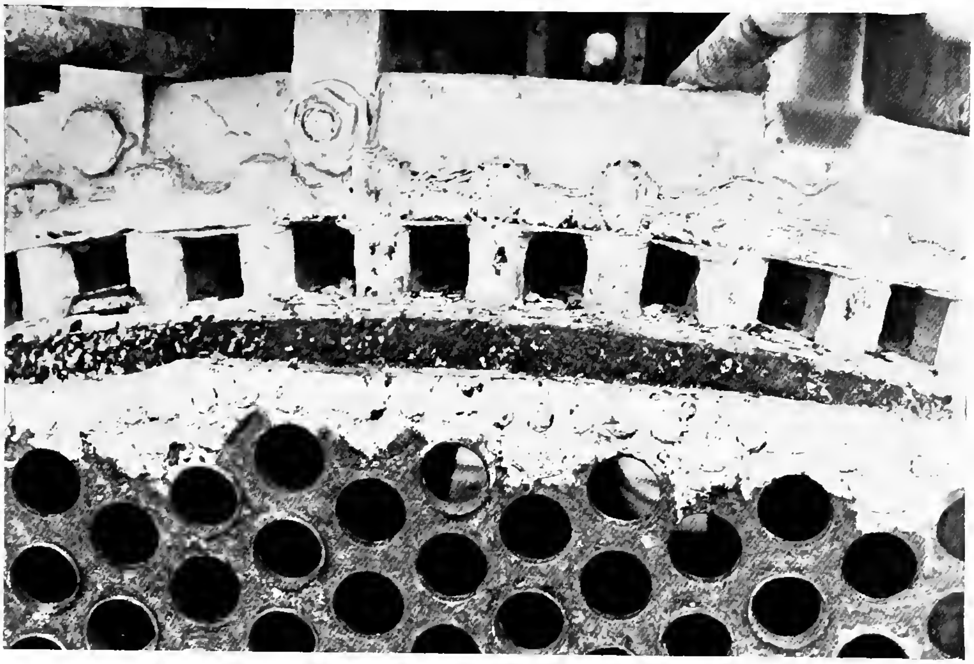

Fig. 10.—Top of flue-sheet showing a patch which has been properly applied, but which has itself become cracked as a result of strains.

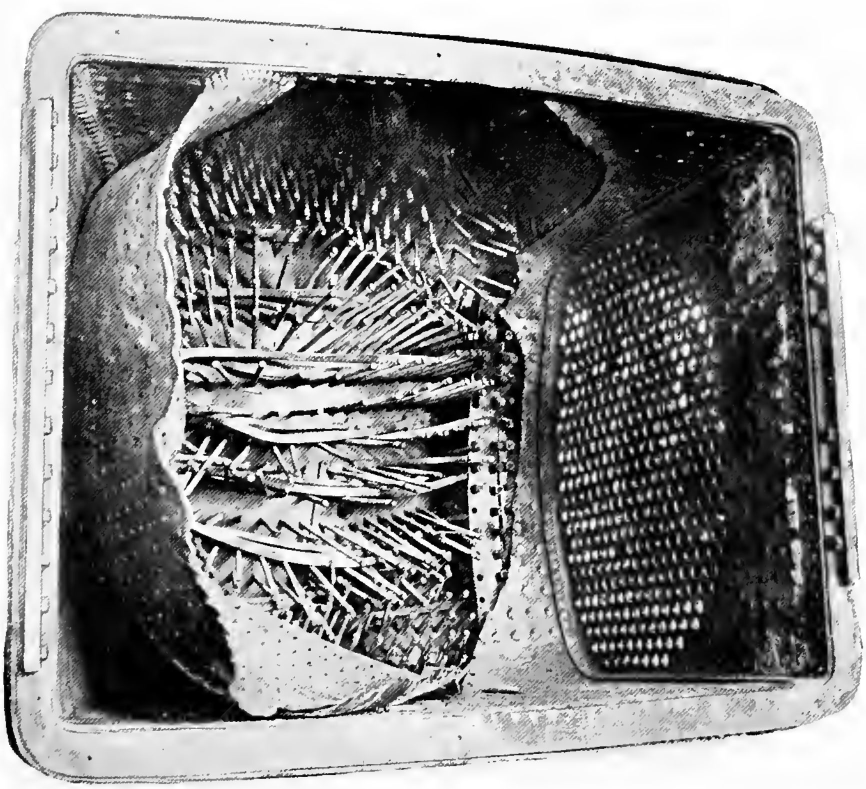

Fig. 11.—Crown-sheet failure in which most of the crown and a portion of one side-sheet were blown away, the stays retaining their places in the out-sidesheet.

higher plane than that occupied by the locomotive boiler. The locomotive service is in need of a boiler possessing the elements of safety which are to be found in existing types of stationary boilers.

22. These well-known deficiencies of the radial-stay boiler are not rehearsed for the purpose of obscuring its merits, but that our devotion in fostering it may not be permitted to blind our eyes to its frailties. No one who considers the progress of the past can assume for a moment that our present-day practice is final. The radial-stay boiler has had its predecessors and they have disappeared, and no one can doubt that the radial-stay boiler itself is but an embryo predecessor of a type which must soon be revealed.

V. The Jacobs-Shupert Boiler and Some of the Advantages Which Have Been Claimed for It*

23. The term Jacobs-Shupert boiler as hereinafter used implies a boiler having a Jacobs-Shupert firebox. This firebox is more than a mere modification of pre-existing forms; it is entirely new in its contour, in the means which are employed for its support, and in the fact that it is made up of a considerable number of comparatively small plates. A Jacobs-Shupert firebox may have the same overall dimensions as a radial-stay or a crown-bar firebox; that is, it may be designed to respond to all of the limitations which must be observed where other types of fireboxes are used. On the other hand, indications are not lacking to show that the dimensions of the Jacobs-Shupert boiler may be extended to limits which are hardly possible in the case of the radial-stay type.

24. The contour of the Jacobs-Shupert firebox as shown by any longitudinal section is not dissimilar to that of the corrugated furnaces so long and so generally used in marine service. It is shown by Fig. 16. The firebox is supported in part from the shape which is given the several

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* As a matter of historical interest, the following brief account has been abstracted from a very full and interesting statement prepared by Mr. H. W. Jacobs. The conception of a sectional firebox having submerged seams originated with Mr. F. W. Shupert while Foreman of Boiler Makers at the San Bernardino Shops of the Santa Fe Railway. He availed himself of an early opportunity to discuss the matter with Mr. H. W. Jacobs, and in April, 1906, a model in tin, having the sections run longitudinally, was made (Figs. 12 and 13). In August of the same year, chiefly through the activities of Mr. Jacobs, the first model having transverse sections extending from mud-ring to mud-ring was constructed (Figs. 14 and 15). This and subsequent models were exhibited by Mr. Jacobs to various people who were likely to be interested, and from whom he expected to get useful suggestions, often with results which were discouraging to him. But in the spring of 1907, he had succeeded in developing the idea to a point where he was ready to apply for a patent. A very complete model to scale, constructed to show the practicability of the design, was exhibited a year later and won many friends for the new device. Encouraged by Mr.

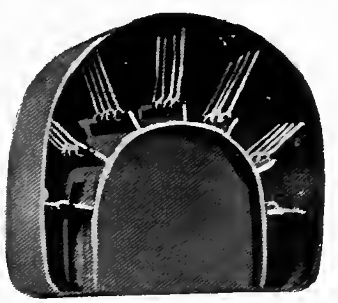

Fig. 12.—Model No. 1. Shupert's original design of firebox. View showing arrangement of stays in first model. March, 1906.

Fig. 13.—Model No. 1. Shupert's original design of firebox. View showing arrangement of longitudinal unit sections in final model. March, 1906.

elements entering into its construction and in part by stay-sheets extending between the sections and the outside shell of the boiler. There are no sling stays in the boiler, and stay-bolts are used only in the door-sheet and tube-sheet.

25. The sides and crown of the Jacobs-Shupert firebox are composed of a series of channel sections made up from long, narrow, flat-sheets which, having been heated, are pressed into shape by a special hydraulic flanging machine (Fig. 17). A flanged section is shown by Fig. 18. Stay-sheets are fitted between every two adjacent sections and find their support in the sections of the outside wrapper of the boiler. The two adjacent sections of the firebox and their stay-sheet are fastened by through rivets. The process of riveting is shown by Fig. 19, and a firebox with all the inside sections in place by Fig. 20. The sections have a uniform width of $9\frac{5}{8}$ inches over flanges and the stay-sheets are $\frac{3}{8}$ of an inch thick, so that each stay-sheet and its accompanying section cover the construction of a 10-inch length of firebox. A firebox having ten sections is, therefore, 100 inches in length, and one having 13 sections is 130 inches in length. The stay-sheets connect the sections of the firebox with similar sections which form the outside wrapper of the boiler, the construction of which is well shown by Fig. 21. To provide for circulation in a horizontal direction, the stay-sheets are pierced with openings of liberal size (Fig. 22) and as all stay-sheets of a given boiler are made from the same templet, these holes line one with another. The door-

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J. W. Kendrick, Third Vice-President of the Santa Fe Railway, the late W. F. Buck, Superintendent of Motive Power, under date of September 2, 1908, formally authorized the building of a locomotive embodying the Jacobs-Shupert firebox. Many engineers of distinction inspected the boiler of this locomotive while it was in process of construction, and in the spring of 1909, it was described by a number of technical papers. The locomotive with the new boiler made its trial trip on April 9 and went into regular service April 20, 1909. It was subjected to an exhaustive series of road tests conducted by Mr. H. B. MacFarland. Its success encouraged the railroad company to order more fireboxes. In January, 1911, the interests of the inventors and pioneer promoters were taken over by an organization incorporated as the Jacobs-Shupert United States Firebox Company, A. F. Huston, President; H. W. Jacobs, First Vice-President; C. L. Huston, Second Vice-President, and Joseph Humpton, Secretary and Treasurer. In July, 1912, G. H. Pearsall and C. B. Moore were made Vice-Presidents in charge of sales. This company, having offices in New York and Chicago and works at Coatesville, Pa., is now responsible for the manufacture and sale of the new device.

FIG. 14. — Model No. 2. Jacobs-Shupert firebox. View showing arrangement of stays as applied in later model. August, 1906.

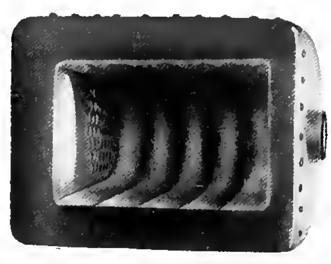

FIG. 15.—Model No. 2. Jacobs-Shupert firebox. View showing arrangement of transverse unit sections in later model. August, 1906.

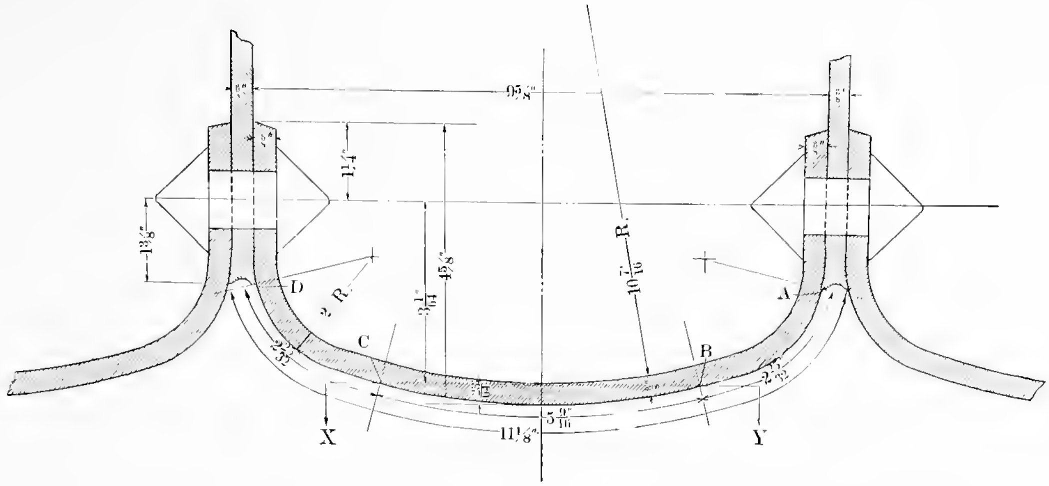

FIG. 16.—View of joint between firebox sections and stay-sheets.

FIG. 17.—Horizontal hydraulic press for flanging channel sections at works of Jacobs-Shupert United States Firebox Co.

sheet (Fig. 23) and the back-sheet of the firebox are stayed to each other in the usual way. There are stays also in that portion of the tube-sheet which is below the tubes. A throat-sheet (Fig. 24) connects the special construction of the Jacobs-Shupert boiler with the barrel which in all respects is normal.

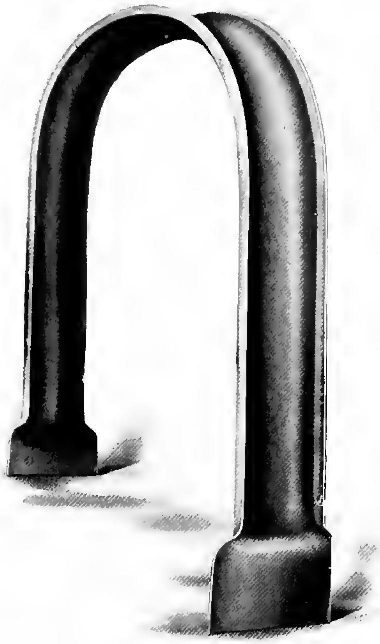

FIG. 18.—Middle inside channel section partially completed.

26. In fitting up the stay-sheets and the inside and outside sections of the Jacobs-Shupert boiler, all rivet holes are drilled from standard templets, so that the process of assembling parts is more like that of assembling a machine than that of putting together the several parts of the boiler. This impression is heightened by the fact that in the mill a long reamer is run through half the flanges of a completely assembled firebox, and then, working from the opposite end, through the other half. All rivets are driven in reamed holes, and rivets in the same horizontal course line with each other perfectly. The mud-ring is in nowise different from that employed in a normal boiler. The method of connecting the sections with the mud-ring is shown by Fig. 25,* and a view of the interior of a completed firebox by Fig. 26.

27. It has been said that objections have been made to the Jacobs-Shupert boiler because of the number of rivets it contains, but before urging such an objection one should consider that a rivet which is well placed and well driven is a very reliable fastening, and that there are no rivets in the side-sheets or the crown of the Jacobs-Shupert firebox where the presence of such fastenings would be most objectionable. The fact that there are no seam-rivets in the firebox, and that all the rivets made necessary by the special construction of

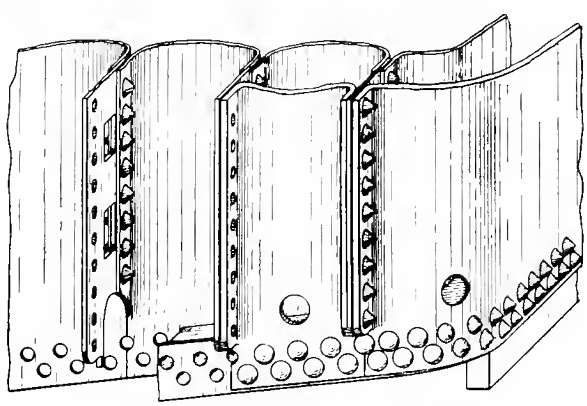

FIG. 25a.—Details of butt-welded joint at mud-ring.

* The latest fireboxes of the Jacobs-Shupert design have what is claimed to be an improved joint between the inside sections at the mud-ring. In this new joint, the lapping of the sections over each other at the mud-ring and around the bottom of

the Jacobs-Shupert boiler are either entirely in the water-space or on the outside of the boiler, suggests that the service to be met by them is similar to that imposed upon the normal shell-rivet. Shell-rivets commonly give no trouble. Moreover, the number of rivets in the Jacobs-Shupert boiler is not greatly in excess of the combined number of rivets and stays in older types of boilers. For example, a comparison of the drawings of the two boilers described in Chapter VII, the heating-surface and external dimensions of which were designed to be exactly the same, shows that the number of rivets, stays, etc., for all that portion of the boiler back of the center of the throat-sheet is as follows:

	Jacobs-Shupert	Radial-stay
In mud-ring	320	312
Connecting inside and outside sections and stay-sheets (11 sections, 12 joints)	2,520	
As fastenings for longitudinal stays	176	164
Patch bolts in door-sheet	44	44
Stay-bolts in tube-sheet and door-sheet	368	366
Rivets in firebox seams		180
Seam-rivets in outside wrapper		373
Radial-stays, crown-bar stays, and stay-bolts not including those in tube-sheet and door-sheet		1,196
Total	3,428	2,635
Reduction in firebox rivets and stays in contact with fire by Jacobs-Shupert construction— 1,196 + 366 + 180 — 368	1,374	
Increase in number of riveted fastenings involved by Jacobs-Shupert construction— 3,428 — 2,635	793	

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the stay-sheet, is eliminated. This new style joint is shown by Fig. 25*a*. Adjacent inside sections are butt-jointed from the point where the stay-sheet ends to the bottom of the mud-ring and this butt-joint is welded by means of the oxy-acetylene method. Fig. 25*b* is a view of a Jacobs-Shupert firebox having the butt-welded joint shown in Fig. 25*a*. This firebox is one of several in service on the Lehigh Valley Railroad.

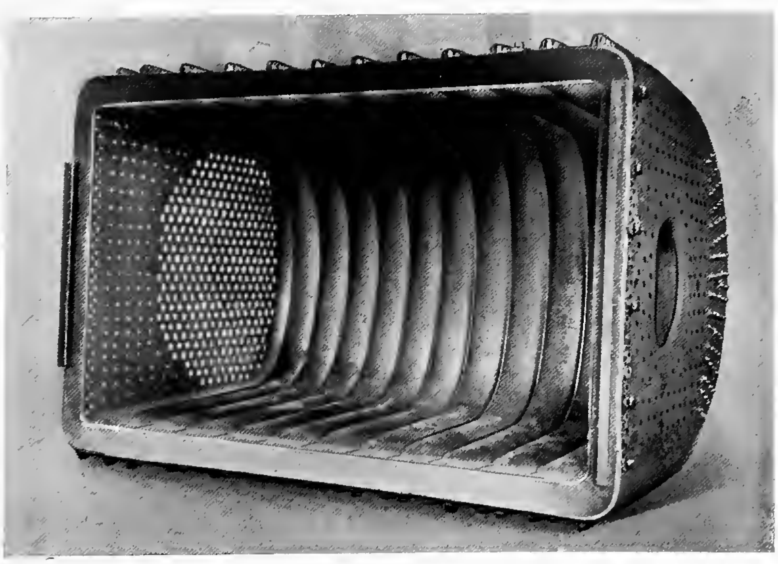


FIG. 25*b*.—Interior of Jacobs-Shupert firebox with butt-welded mud-ring joint. Lehigh Valley Railroad.

The method of riveting sections and stay-sheets has been shown by Fig. 19. Many rivets may be driven in the time that is required to set one stay-bolt, and a rivet in a reamed hole once driven requires no attention, while a stay-bolt must be constantly inspected and frequently worked upon. The elimination, therefore, of 1374 firebox stays in return for the addition of 793 through rivets, is a matter which, from the standpoint of

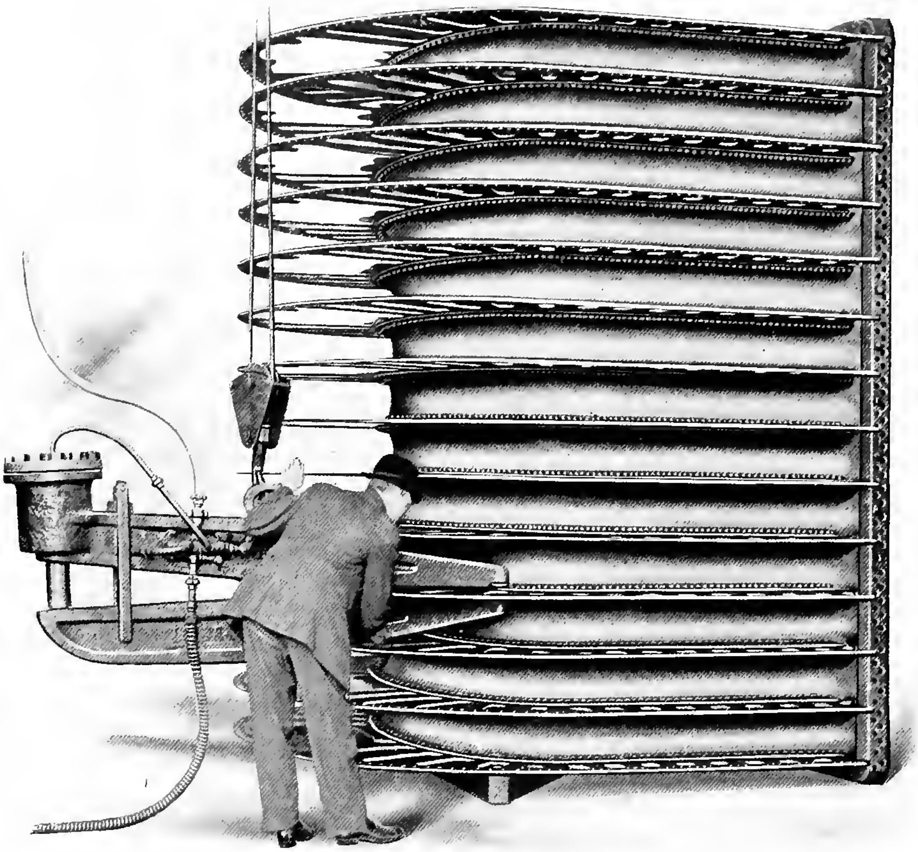


FIG. 19.—Method of riveting together the channel sections and stay-sheets by means of gap riveter.

construction and maintenance, has much to recommend it. Obviously, while the Jacobs-Shupert construction does increase the number of rivets, there is no corresponding increase in maintenance cost or hazard; the change amounts to the displacement of a troublesome device by one of the oldest and most reliable fastenings employed in the arts.

28. A number of advantages possessed by the new form of firebox are at once apparent. Most obvious, perhaps, is the presence of an element of flexibility which is introduced by the combination of curved sections. In this respect the Jacobs-Shupert firebox is comparable with the corrugated furnace to which reference has already been made. Any

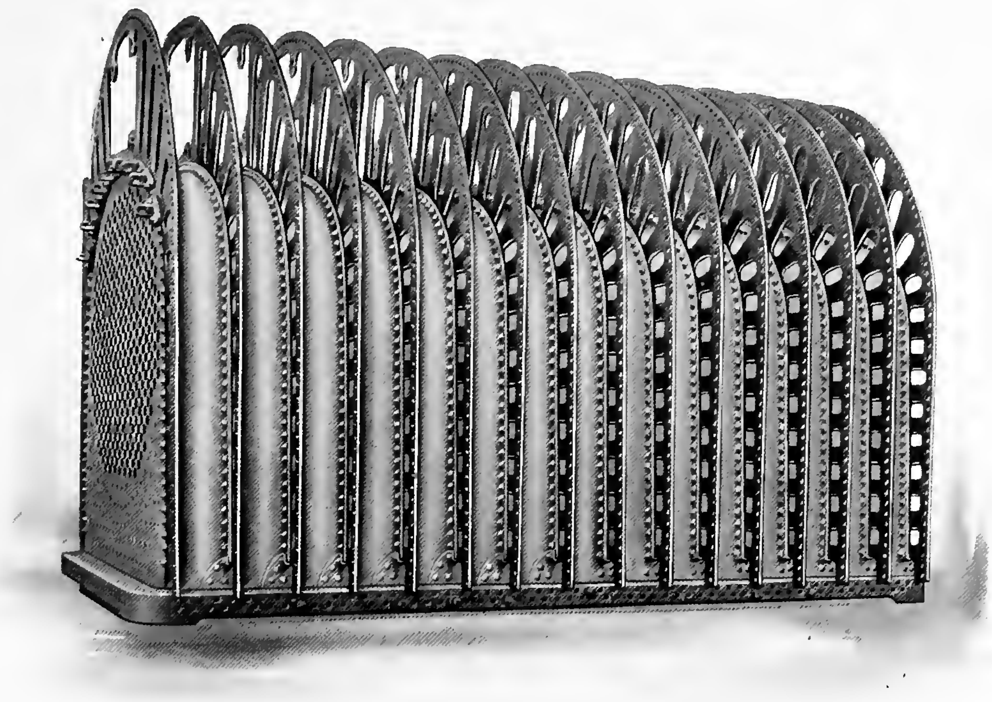


Fig. 20.—The Jacobs-Shupert sectional firebox ready for the application of the outside sections.

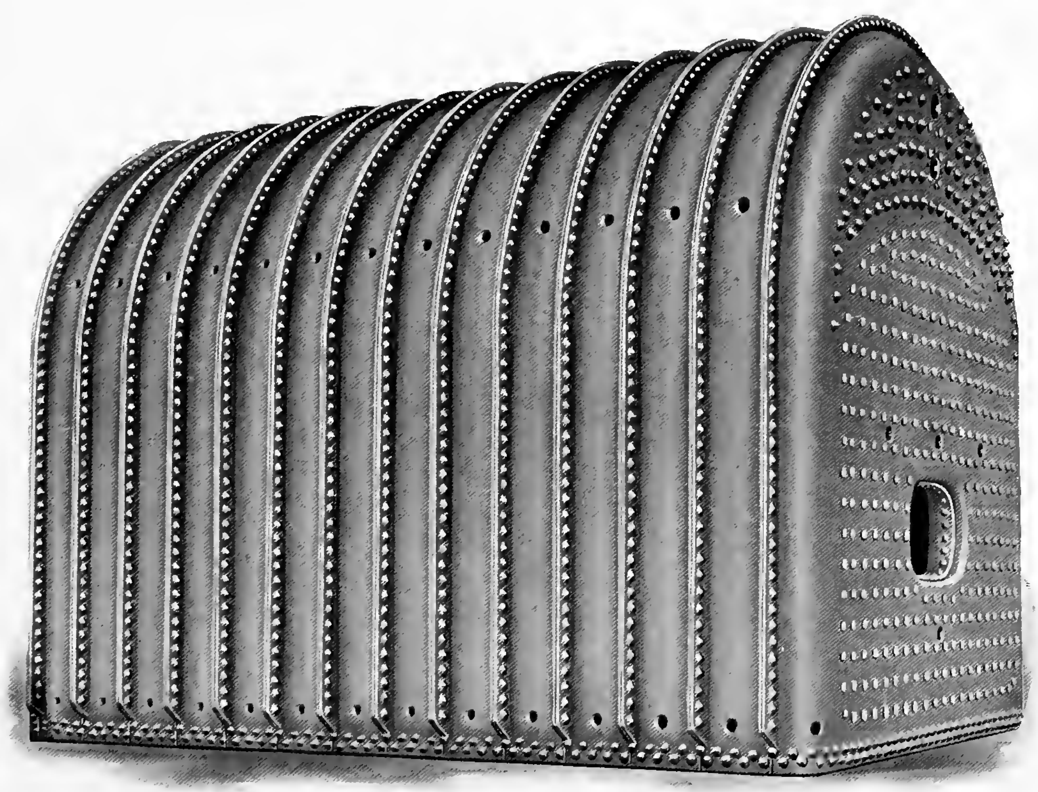


Fig. 21.—The completed Jacobs-Shupert back end ready for application to boiler shell.

strain due to longitudinal expansion is taken care of with the least chance of injury to the structure. The effect of this provision must be beneficial in reducing the cost of repairs and in increasing the life of the boiler.

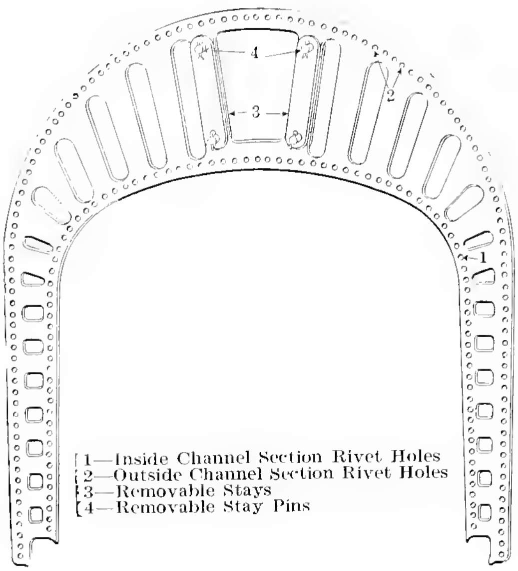


FIG. 22.—Stay-Sheet.

29. The presence of the corrugated surface within the firebox adds somewhat to the extent of the firebox heating-surface as compared with the surface presented by a normal firebox of the same overall dimensions. The extent of this increase in the case of the boilers described in Chapter VII is 11 per cent.

30. The fact that the Jacobs-Shupert firebox has no stay-bolts in the sides and crown removes an important source of difficulty. With no stay-bolts there can be, of course, no leaky bolts to calk, no broken bolts to replace, and no spots inherently weak when the water drops a little low. The rivets joining the several sections making up the firebox structure are not inside of the firebox. They can not be seen from the firebox and they can not be affected by the direct action of the heat from the firebox. They are above the crown in the water space of the boiler at a distance sufficiently far from the heating-surface of the firebox to be undisturbed by any condition that may arise within the firebox. These features place the design of the Jacobs-Shupert boiler upon a plane which, from a purely mechanical point of view, is essentially higher than that which is occupied by the normal radial-stay boiler. The fact also that in the manufacture of these boilers,

FIG. 23.—Looking toward door-sheet of Jacobs-Shupert firebox during process of assembling.

the principle of interchangeability is employed, establishes a standard of workmanship which has never before been reached in the construction of large boilers. This superior workmanship will not in the long run increase the cost. Interchangeability in machine construction has operated to improve the quality of the machine and also to reduce its cost. Similar results will ultimately follow the adoption of interchangeability in boiler construction. In the manufacture of the Jacobs-Shupert firebox, machinery is used instead of men. Each operation is simple and yet the result is precise. There is no drifting of holes and no local heating of plates which have been set in their places in the boiler. The result of the new process is a boiler accurately made, substantially put together, and comparatively free from initial strains. The design and the methods of manufacture combined permit repair parts to be carried, and provide an inexpensive procedure in maintenance.

Fig. 24.—Straight throat-sheet showing jig bolted in place ready for drilling rivet holes.

31. The Jacobs-Shupert boiler judged by the standards of good design is obviously less susceptible to the weakening influences of low-water conditions than the radial-stay boiler. In the Jacobs-Shupert boiler the fastenings which must be depended upon to hold up the crown are so far removed from the heat as to be comparatively unaffected; whereas, in the radial-stay boiler they are actually in the fire. Its superiority in this respect, while apparent as a matter of design, has now been abundantly demonstrated by the results of tests under low-water conditions, described in Chapter XI.

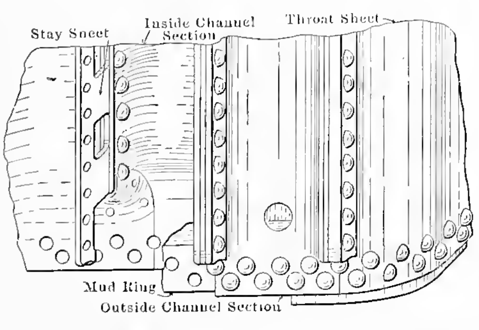


Fig. 25.—Method of lapping the joints and making the connection at the mud-ring.

32. As a safety device, the Jacobs-Shupert firebox derives from its sectional form the same advantage which the water-tube boiler derives from the subdivision of its heating-surface into tubes of moderate size. If for any reason, such as the occurrence of low water or the accumulation of scale, the firebox fails, the worst thing

which can happen is the blowing out of a single section. In this case the plate will "pocket," and the rent will be small. The result will not be an explosion, but merely a discharge of steam and water into the firebox

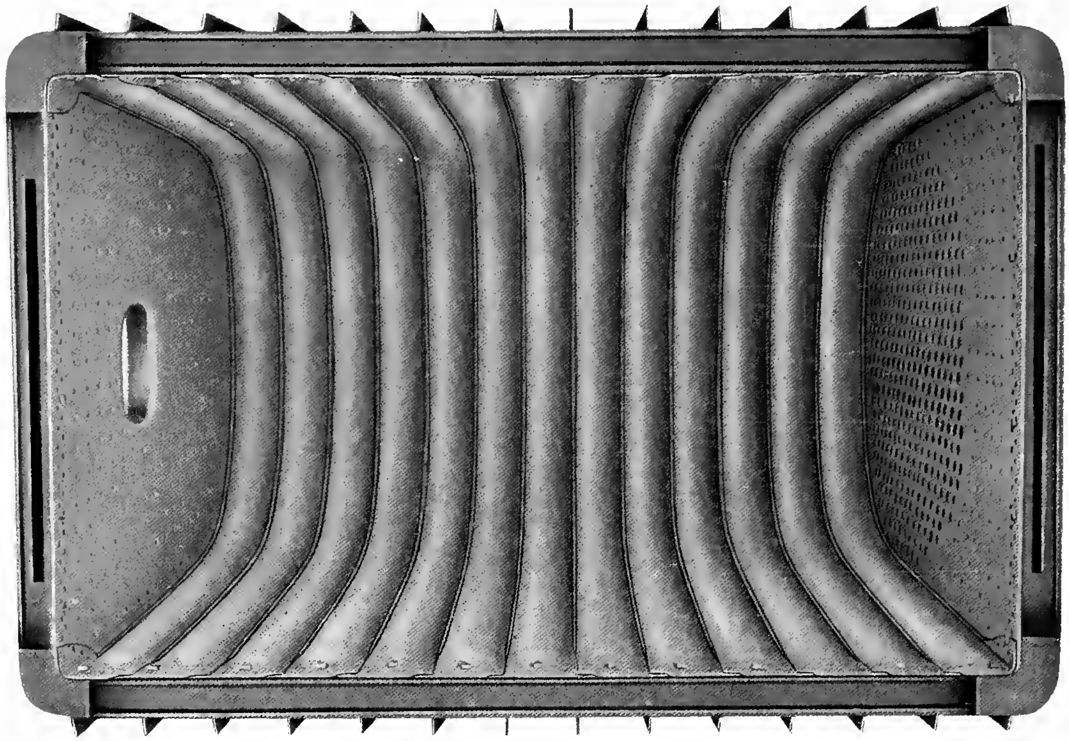


Fig. 26.—Looking toward crown of Jacobs-Shupert firebox.

which extinguishes the fire and relieves the boiler from pressure without doing serious injury to life or surrounding property. The Jacobs-Shupert boiler may, in fact, properly be characterized as a "safety boiler."

VI. The Jacobs-Shupert Boiler in Service

33. Having agreed to make a study of the Jacobs-Shupert boiler, it became desirable for the undersigned to make use of such sources of information concerning this new type of boiler as were open to him. One conspicuous source was to be found in the one hundred and sixty-nine locomotives having Jacobs-Shupert boilers, which were in service along the line of the Santa Fe Railway. It was determined, therefore, as a preliminary to the more scientific aspects of the study, to make a trip of inspection for the purpose of ascertaining the behavior of the boilers as they were to be seen when in service on that road. In carrying out this purpose, inspections were made late in November, 1911, at the Argentine shops near Kansas City, at the principal shops of the road in Topeka, Kansas, at the roundhouse at Newton, Kansas, and at the roundhouse and shops at Clovis, New Mexico, at each of which points a considerable number of Jacobs-Shupert fireboxes were handled. A Mallet-compound fitted with a Jacobs-Shupert firebox was also ridden on the division west of Clovis.

34. The Argentine roundhouse was found to be handling twenty-five Jacobs-Shupert fireboxes. Most of these at the time of my visit were out on the road, but two were found in such condition as to admit of internal inspection. These were the boilers of locomotives Nos. 1485 and 1494. Both locomotives were equipped for using oil fuel, and both were reported as having been in service about a year. The sections of the firebox of locomotive No. 1485 were in perfect condition, and nothing could be found either upon them or upon the joint between them and their stay-sheets to indicate that they had ever been worked upon subsequent to their installation. Some calking had been done in the joint between the forward section and the tube-sheet and work had been done on the tubes, but the structure of the firebox was in excellent condition. The presence of brick-work common in oil-fired locomotives prevented a close inspection in the vicinity of the mud-ring, but no indication of leaks at that point could be discovered. Locomotive No. 1494 was found in a similar favorable condition. Its tubes were tight and all parts of its firebox perfect. The boiler had just been washed out, and it was possible by inserting electric lights through the washout holes to see a good deal of the water side of the sections. They were found evenly coated with a thin scale, presenting no signs of rust, of pitting, or of other forms of local deterioration. In this roundhouse also the interior of the firebox of locomotive No. 1460 was examined. This locomotive is in all respects similar to those already described, except that it is fitted with a radial-stay firebox. It was in the same service as those previously examined, was being fired with oil

as were they, and was said to have been in service for about twenty months. The tubes and a good many stays widely distributed over the firebox were leaking slightly, but the firebox was otherwise in good condition. The boiler was cold and a boiler maker was inside calking staybolts. Oil firing is likely to be hard in a locomotive firebox, and this boiler was older than the Jacobs-Shupert boilers previously examined, but after making all allowances, one could not escape the impression that in their resistance to the deteriorating influences of service, the Jacobs-Shupert fireboxes were disclosing superior qualities.

35. At the Topeka shops there was an opportunity to inspect the oldest Jacobs-Shupert firebox in service. It was on the Santa Fe type, locomotive No. 917. It had been in heavy service, oil-fired, for a period of two and a half years and was at the time of inspection undergoing heavy repairs. The necessary work on the boiler had been completed, but work on the machinery was still in progress. An examination of the firebox showed that some small cracks in the upper part of the tube-sheet had been plugged in the course of service repairs. The repeated rolling of tubes had had the usual effect of extending the tube-sheet upward, and the firebox section attached thereto had rolled up with it without injury. The firebox of this boiler was a large one, it being made up of thirteen sections. As a result of overheating, due doubtless to accumulations of scale, small pockets had formed on the first six of them, counting from the tube-sheet back. At the time of inspection these had been heated and set back in the process of repairing, and as some small transverse cracks had appeared, the oxyacetylene flame had been used to add metal and to weld up the defects. The area of surfaces on the several sections which had been thus treated varied from a half inch to two inches in diameter. By this simple process a damaged crown had been made entirely good. The sections were in perfect form and it was said that the boiler had been subjected to a hydrostatic test of 350 pounds. These facts are important as disclosing the ease with which the new type of firebox, after suffering damage, may be repaired. At the Topeka shops I inspected also the interior of the firebox of locomotive No. 3009, a new Mallet-compound which went into service only three months previous to my visit. This locomotive was in the shop after having been in a head-end collision. Its firebox is the largest in service, being made of fifteen 10-inch sections, making its length 150 inches. The condition of this firebox was perfect.

36. The Pecos division of the Santa Fe is equipped for its freight service with forty or more very heavy Mallet-compounds. All of these have Jacobs-Shupert fireboxes. They are fired with coal and work heavy trains over long grades. The feed-water is alkali, and it is necessary to cool, empty and refill all boilers after every round trip. Locomotive No. 1162 was ridden from Clovis to Blacktower. The train consisted of 42 loaded cars and a caboose. The atmospheric temperature was about

freezing, and the entire distance was up a 0.6 per cent. grade. In a five-mile run the engine had accelerated its train to a speed of 25 miles an hour. The rate of firing during this portion of the run was not far from 5,000 pounds of coal an hour. The steam pressure which was 210 pounds at the start, increased during the first five miles run to 225. These conditions, I understand, are typical of those which determine the service which must be withstood by the Jacobs-Shupert firebox in the Mallet-compounds of the Pecos district.

37. At Clovis, a division point in the Pecos district, an inspection was made of the interior of the fireboxes of two of these locomotives, No. 1158, which went into service nineteen months ago, and No. 1162, which has been in service about one year. No. 1158 had been in the roundhouse but a short time and was in the process of being cooled off. No. 1162 was cool, and the boiler maker was giving attention to three tubes which showed slight leaks. With this exception, both fireboxes were in perfect condition. No sign of a leak could be discovered about the mud-ring or between the sections or elsewhere within the structure of the firebox. Taking advantage of the fact that the construction of the Jacobs-Shupert firebox permits every part of the water side of the crown-sheet in a boiler ready for service to be closely inspected, a process impossible of execution in a stayed firebox, the water-space of No. 1162 was carefully examined. The tubes of the boiler presented rust spots or incipient pits, due doubtless to the nature of the feed-water used, and at rare intervals similar spots appeared on the sections of the firebox. Except for this, the water surfaces were perfect. There was no evidence of localized rust-spots on the sections of the firebox. At Clovis also a stay-bolt firebox on the balanced compound passenger engine No. 530 was inspected. This boiler was reported to have been in service about one year. Many of the stay-bolts had been worked upon and many had lost their heads. The stay-bolts along the lower portion of the side-sheets were seeping and the plate was beginning to bulge between stays.

38. The inspection at Clovis ended the detailed examinations of fireboxes. The five days' experience on the line of the Santa Fe justifies the following conclusions:

1. The construction of the Jacobs-Shupert firebox admits of easy and thorough inspection.

2. The Jacobs-Shupert firebox gives no trouble by leaking at the mud-ring. Not a single case of a leaky mud-ring could be found.

3. The fireboxes give no trouble by leaking between sections.

4. No indication could be found of grooving or cracking at the fillet or in any other part of the sections making up the firebox.

5. The fireboxes examined, while very large, appear to resist perfectly the pressure imposed, which in all cases was above 200 pounds.

6. The firebox structure of a Jacobs-Shupert boiler after a year of service in a district of alkali water, appeared as though new, while that

of a radial-stay boiler in the same service for the same or a lesser length of time presented unmistakable evidences of degeneration.

7. Evidence was not lacking to prove that minor defects, such as those which may arise in a Jacobs-Shupert boiler from accumulation of scale or because of low water, are easily repaired.

Since the inspection of the undersigned, that is, since November, 1911, it has been reported that defects have appeared in some of the older Jacobs-Shupert boilers. These have arisen from a faulty arrangement of longitudinal stays. In the boilers affected the back head is braced by comparative short stays secured to certain of the outside or wrapper-sheet sections. The sections being curved are not well suited to meet the loads imposed by the stays, and it is not surprising that some of them have suffered. The obvious remedy is to be found in extending all longitudinal stays through to the throat-sheet or to the barrel of the boiler. By so doing, they will be removed from all connection with the sections. I understand that the present practice of the Jacobs-Shupert company provides for this change in construction.

VII. Program of Tests and a Description of the Means Employed in Carrying it Out

Program of Tests

39. For the purpose of determining the performance of the Jacobs-Shupert boiler as compared with that of a radial-stay boiler, an elaborate series of tests was outlined. The outline embraced the following provisions:

The boilers to be tested were to be designed for locomotive service and to be identical in their general dimensions. They were to differ from each other only in the construction of the firebox and in the means employed for supporting it. One boiler was to be equipped with a Jacobs-Shupert firebox and the other with a radial-stay firebox conforming to the best present-day practice.

A laboratory was to be provided in which the two boilers could be erected and equipped with all apparatus necessary for testing. The tests specified were to be grouped into three series designated as Series A, B, and C, respectively.

Series A was planned to disclose the relative amount of heat absorbed by the fireboxes and by the tubes of the two boilers under similar conditions of operation. To facilitate these tests, it was proposed to have the boilers constructed with a partition separating the water space into two compartments, one of which was to include the firebox surface and the other the tube surface. In carrying out the tests, these compartments were to be separately fed with weighed water. Not less than three tests, one at low power, one at medium power, and one at high power, were to be made upon each boiler. It was believed that the results would serve to establish the relative value of a unit area of firebox heating-surface as compared with that of a unit area of tube heating-surface, facts which American engineers have long desired to know, and that they would disclose the difference, if any, in the heat-absorbing capacity of the two fireboxes tested.

Series B was to be made up of tests of normal boilers. The boilers which had served in the tests of Series A were to undergo such reconstruction as might be found necessary to the removal of the partitions. This accomplished, there would be available for the further work a normal Jacobs-Shupert boiler and a normal radial-stay boiler. Each boiler was then to be subjected to a series of evaporative tests for the purpose of establishing its evaporative efficiency and capacity under different rates of power. In addition to data usually secured in boiler testing, it was proposed to make of record such information as might be possible concerning the circulation of water within the two boilers. The purpose of this series was to secure an accurate measure of the evaporative performance of the Jacobs-Shupert boiler and of a normal radial-stay boiler.

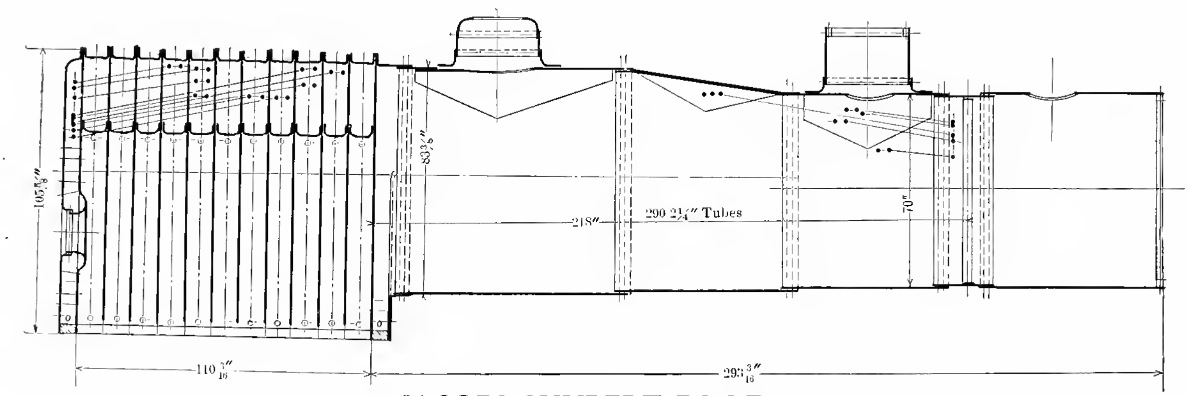
Series C was planned to disclose the relative strength of the two boilers under low-water conditions. In preparation for the tests of this series the boilers were to be removed from the testing laboratory and set up with everything necessary to their operation in a location where their

explosion would result in no harm to surrounding property. Adequate provisions were to be made for the safety of observers. The boilers were to be operated, the supply of feed-water was to be cut off or so controlled that the firebox would be uncovered, and the low-water conditions were to be continued until failure occurred.

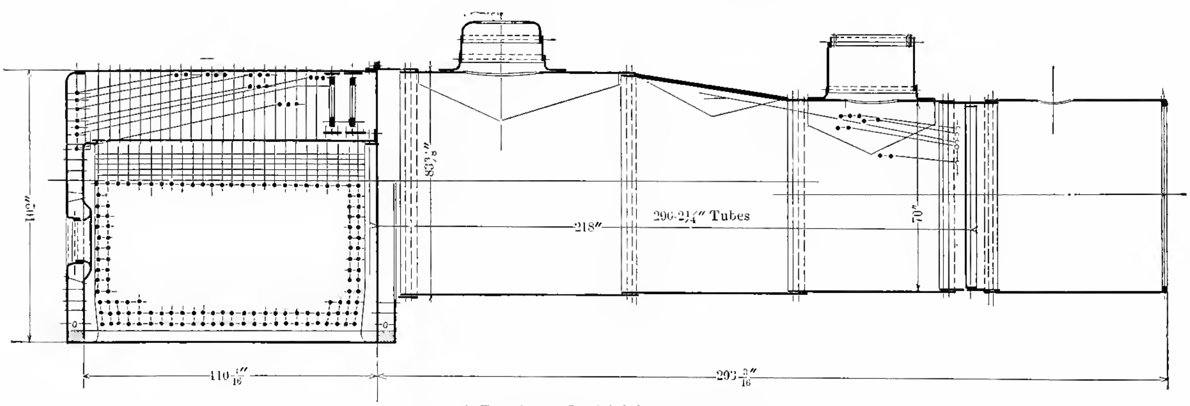
The tests contemplated by this outline have now been entirely carried out. It is the purpose of the present chapter to present in detail a description of the boilers and of the apparatus and methods employed in testing them.

Design of the Boilers

40. The boilers tested are shown in their general dimensions by Fig. 27. Drawings showing the detailed construction of both boilers are presented as Figs. 28 to 36, inclusive. The firebox-end of the Jacobs-Shupert



JACOBS-SHUPERT BOILER



RADIAL-STAY BOILER

Fig. 27.—General construction of test boilers.

boiler was taken at random from a lot which were under construction for a railroad company. No effort was made to have the particular one chosen stronger or better than the others which were going through the shop. In its dimensions and in the specifications which controlled in its construction, it conformed to the requirements of the railroad company in question. The boiler complete was made by the Jacobs-Shupert United

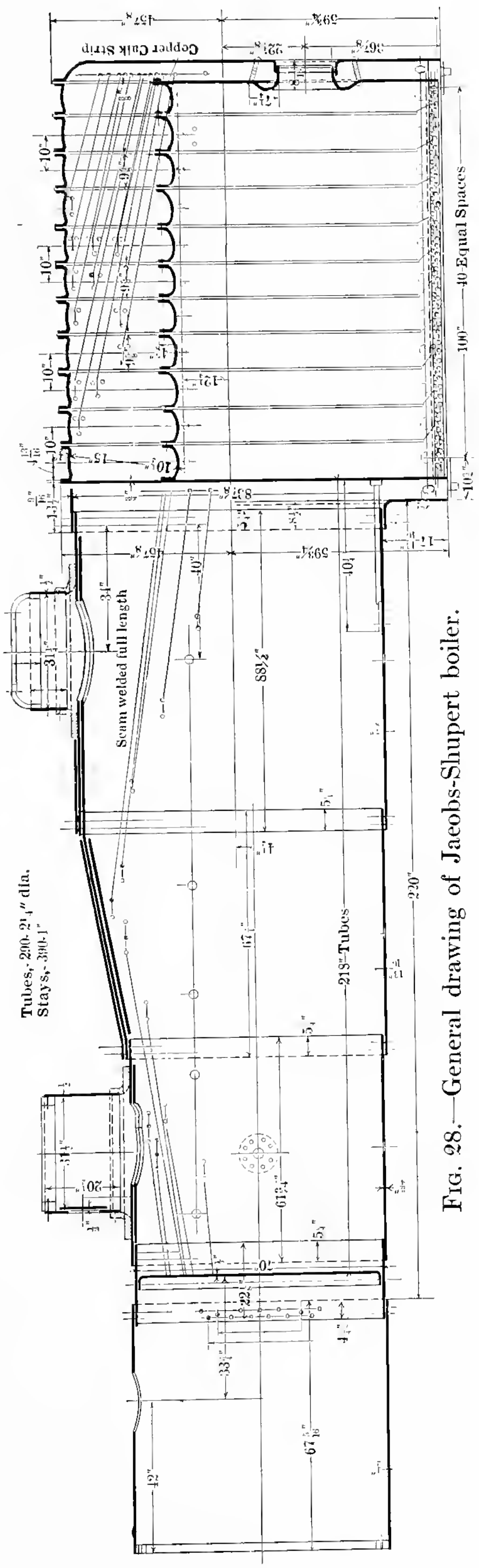


FIG. 28.—General drawing of Jacobs-Shupert boiler.

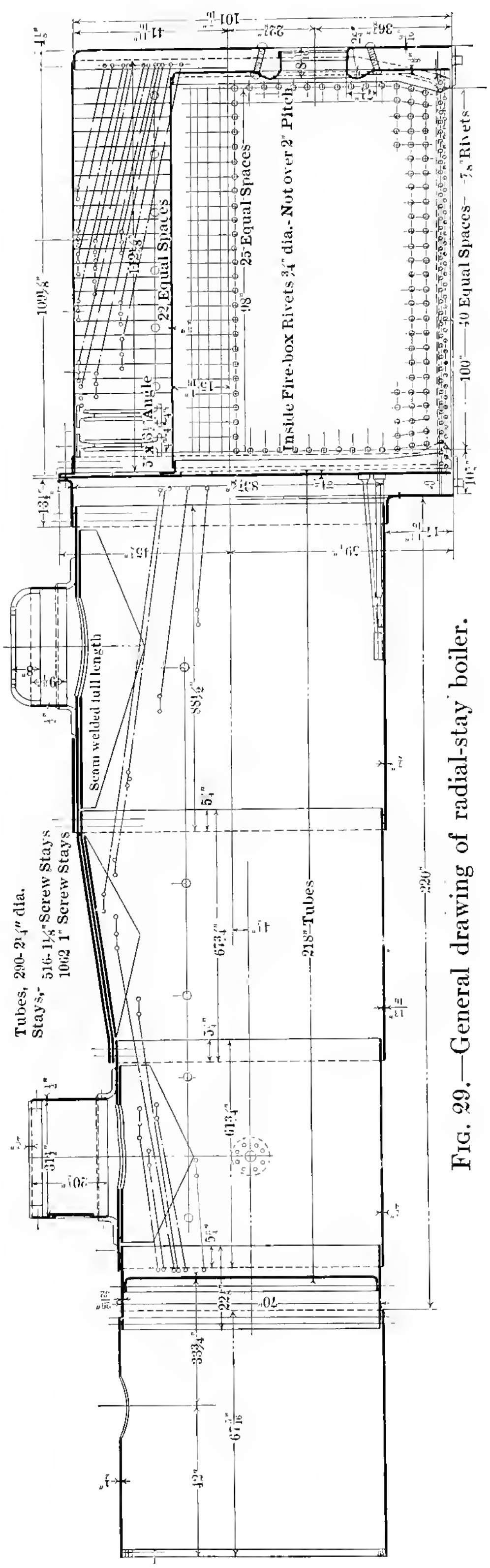


FIG. 29.—General drawing of radial-stay boiler.

States Firebox Company at Coatesville, Pennsylvania. In order to secure a radial-stay boiler of the same general dimensions as the Jacobs-Shupert boiler, it was found necessary to build one especially for the tests. The order was executed by The Baldwin Locomotive Works, subject to the specifications and standards of the same railroad to which the Jacobs-Shupert fireboxes were being supplied.

41. In addition to the inspection of the railroad company, both boilers were built in the presence of a personal representative of the undersigned. All materials employed were subject to the usual inspection and test, and a record of these tests is in the possession of the undersigned. Reports were received daily as the work progressed. The whole purpose was to secure two boilers, each of which should be entirely representative of the type it was designed to represent. The purpose was to secure a normal Jacobs-Shupert boiler and a normal radial-stay boiler.

42. The dimensions of the boilers are as follows:

	Jacobs-Shupert Boiler	Radial-stay Boiler
Type of boiler	Extended wagon top	Extended wagon top
Draft appliances	See Fig. 44	See Fig. 44
Grates, oil burner, brickwork, brick arch	See Figs. 45 and 46	See Figs. 45 and 46
Boiler Shell—		
Diameter at front-end	70″	70″
Diameter at throat	83⅞″	83⅞″
Tubes—		
Number	290	290
Length	18′ 2″	18′ 2″
Diameter	2¼″	2¼″
Firebox—		
Length, inside	9′ 1⅝″	9′ 1 11/16″
Width, inside	6′ 4⅜″	6′ 4¼″
Depth, inside	6′ 1 7/16″	6′ 2 13/16″
Grate area, square feet	58.14	58.07
Heating Surface—		
Side- and crown-sheets, projected area	146.2	146.6
Side- and crown-sheets, developed area, used in all computations	168.0	146.6
Back tube-sheet	28.9	27.5
Door-sheet	33.9	32.6
Total firebox	230.8	206.7
Tubes	2759.0	2759.0
Front tube-sheet	18.6	18.6
Total barrel	2777.6	2777.6
Total boiler	3008.4	2984.3
Distribution of heating-surface applicable to tests of partition boiler (Series A)—		
Side and crown-sheets	168.0	146.6
Door-sheet	33.9	32.6
Total surface effective in transmitting heat to firebox end	201.9	179.2
Tubes	2759.0	2759.0
Front tube-sheet	18.6	18.6
Back tube-sheet	28.9	27.5
Total surface effective in transmitting heat to barrel end	2806.5	2805.1

	Jacobs-Shupert Boiler	Radial-stay Boiler
Ratio of total firebox surface to surface effective in transmitting heat to firebox-end	1.14	1.15
Thickness of Boiler Sheets—		
Smoke-box	½″	½″
Shell, joint ring	$\frac{23}{32}$″	$\frac{23}{32}$″
Shell, front section	¾″	¾″
Shell, middle section	$\frac{13}{16}$″	$\frac{13}{16}$″
Shell, back section	⅞″	⅞″
Shell, throat-sheet	⅞″	⅞″
Shell, front flue-sheet	½″	½″
Firebox, crown-sheet	⅜″	⅜″
Firebox, side-sheets	⅜″	⅜″
Firebox, back sheet, inside	⅜″	⅜″
Firebox, back sheet, outside	$\frac{9}{16}$″	$\frac{9}{16}$″
Firebox, outside wrapper sheet	½″	½″
Firebox, section, stay-sheets	⅜″	
Firebox, back flue-sheet	$\frac{9}{16}$″	$\frac{9}{16}$″
Firebox Sections—		
Number	11	
Width	10″	
Boiler Stays—		
Crown-bars, number		2
Crown stays, diameter		1⅛″
Button head, stays, rows		10
Crown bolts, diameter		1⅛″
Stay-bolts, diameter		1″
Rivets, Size—		
Boiler shell	1¼″	1¼″
Firebox, inside	¾″	¾″
Firebox, outside	1″	1″
Mud-ring	1″	1″

43. In Series A each boiler was divided into two distinct compartments by the introduction of a partition between the firebox and barrel. The partition was simply a back tube-sheet extended as a single flat plate (Fig. 30) to the wrapper-sheet and mud-ring, and riveted in place between the firebox and barrel. These partitions in position as they appear from the barrel of each boiler are shown by Figs. 37 and 39. In Series B the regular flue-sheet was employed, which necessitated the removal of the partitions. This was readily accomplished in the Jacobs-Shupert boiler by cutting openings through the partition with oxyacetylene flame, thus transforming the partition into a flue-sheet normal in form for this type of boiler. Fig. 38 shows this flue-sheet viewed from the barrel of the boiler as used in Series B.

44. The removal of the partition in the radial-stay boiler was a more difficult matter. In this boiler the back tube-sheet was connected with the side-sheet and crown of the furnace through the introduction of an angle-iron, and it extended to the outside shell of the boiler and was secured thereto between an angle on one side and the throat-sheet on the other side. To make a satisfactory job it was found necessary to remove the whole sheet. The rivets between the firebox and the angle were cut, and the acetylene torch was used to cut out the sheet just inside of the

shell, leaving the construction in the form shown by Fig. 40. A new tube-sheet was thus inserted as shown by Fig. 41.

44*a*. In retubing the boilers after the reconstruction of their fireboxes, all tubes were welded into the firebox tube-sheet. This was done in anticipation of the low-water tests (Series C) which were to conclude the experimental work. This precaution was taken because low-water sometimes allows the tube-sheet to be forced off the tubes with the result that the failure is a tube-sheet failure. It was the particular purpose of the low-water tests, which were anticipated, to subject the crown of the firebox to conditions so severe as to bring about its failure, and it was thought best

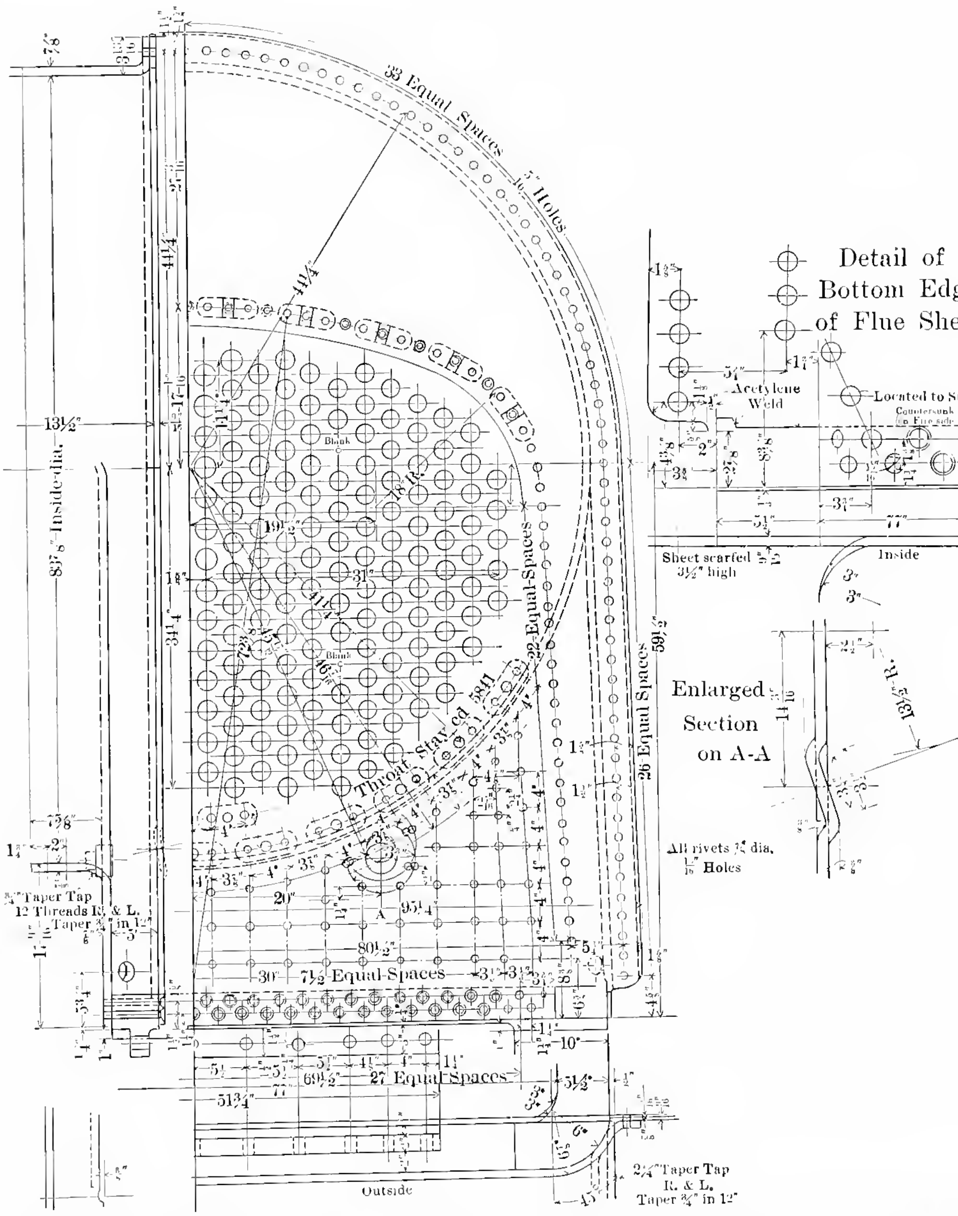


Fig. 30.—Detail drawing of extended back tube-sheet forming partition between firebox and barrel.

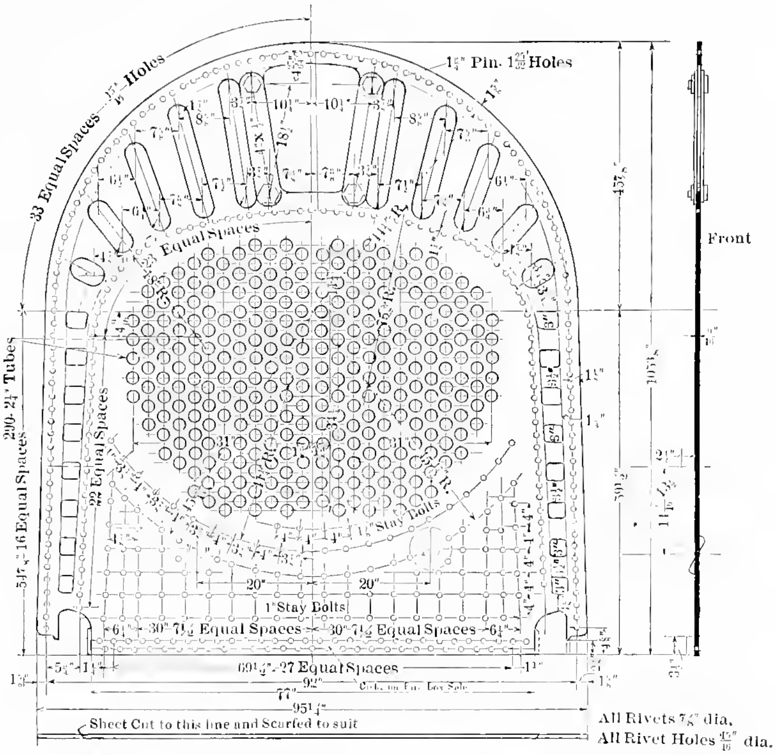


FIG. 31.—Detail drawing of back tube-sheet, Jacobs-Shupert boiler.

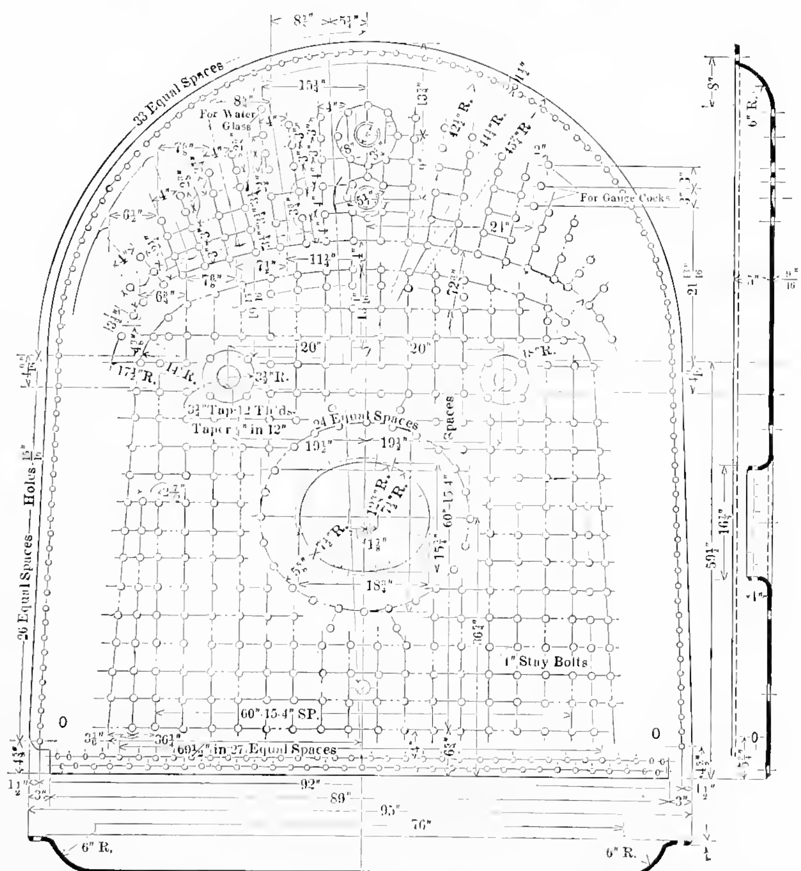


FIG. 32.—Detail drawing of back head, Jacobs-Shupert boiler.

to take every precaution to prevent this process being interfered with by a premature failure of the tube-sheet. The advantage which might accrue if the practice of welding the tubes were more general is to be seen in the fact that throughout the tests of Series B which followed the refitting, the tubes were always tight. The resistance of the welded tubes to overheating under low-water conditions is referred to in connection with Chapter XI in which the low-water tests are described.

The Arrangement of the Laboratory

45. The boilers having been completed, they were installed in a temporary building erected to receive them on the grounds of the Lukens Iron & Steel Company. They were erected side by side and each was equipped for testing independent of the other. The general arrangement

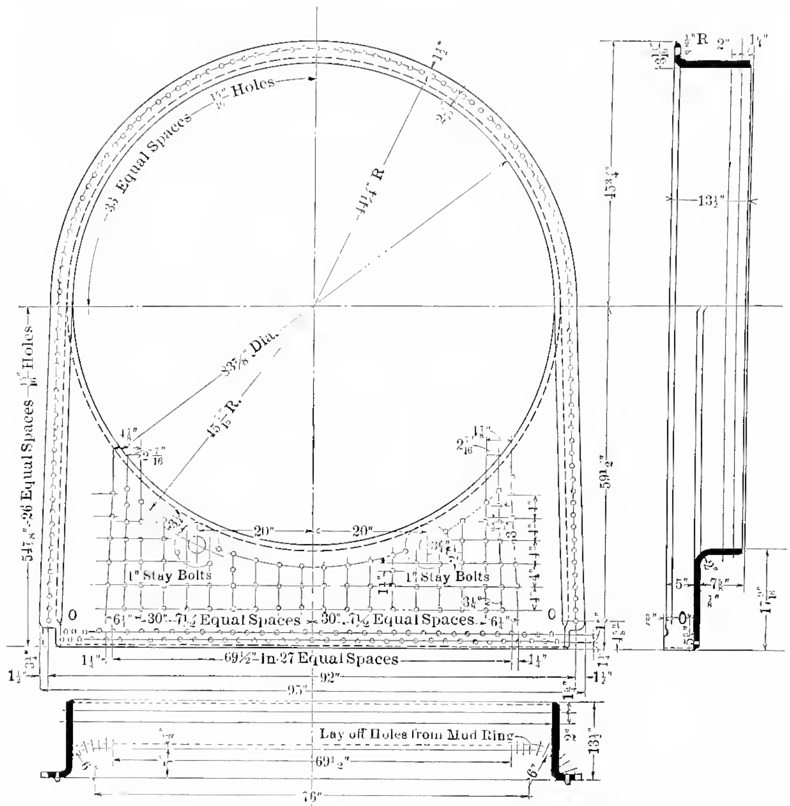


FIG. 33.—Detail drawing of throat-sheet, Jacobs-Shupert boiler.

of the boilers and their accessory apparatus as installed when oil was used as fuel is shown by Fig. 42. A similar view (Fig. 43) shows the arrangement as installed when coal was used as fuel. The piping for one of the boilers is shown by Fig. 44, the detailed arrangement of brickwork necessary to oil-firing by Fig. 45, and the arrangement of dampers and brickwork for the coal-fired tests by Fig. 46. A series of photographic views of the laboratory are presented as Figs. 47 to 56, inclusive.

46. The boilers were erected on concrete piers. The pier at the fire-box end was given a flat surface and was a foot larger all around than the mud-ring. Four cast-iron pedestals (Fig. 44) served to support the mud-ring of the boiler 12 inches above the surface of this pier. When oil was used as fuel, the necessary brickwork was built up from the pier (Fig. 45), and when coal was used as fuel, the space between the mud-ring and the pier was filled with steel sheets to serve the purpose of an ash-pan (Fig. 46). Dampers in these sheets supplied means for controlling the draft.

47. To permit the boilers to be operated under conditions common

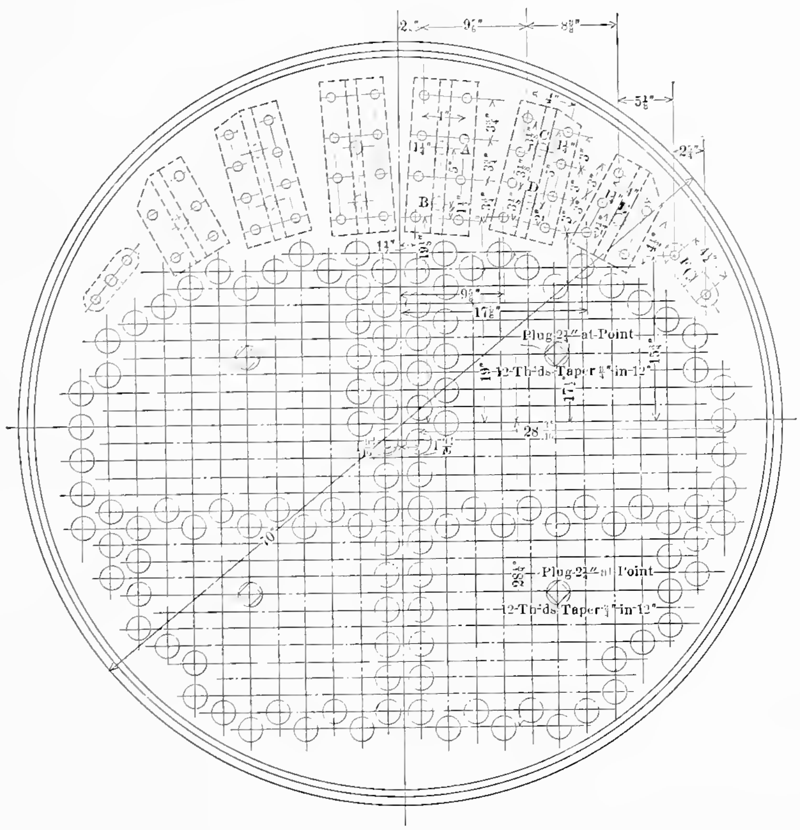


FIG. 34.—Detail drawing of front tube-sheet, Jacobs-Shupert boiler and radial-stay boiler.

in service, they were equipped with a normal front-end arrangement and stack, except that the usual netting was entirely omitted. A normal exhaust pipe and tip was fixed to the bottom of the smoke-box, and suitable outside piping was provided to convey the steam generated by the boiler to the lower end of the exhaust pipe. This arrangement provided for a delivery of most of the steam generated through the exhaust tip, and the steam thus discharged gave rise to the usual draft action. The control of the draft was provided for by a valve in a 7-inch pipe (Figs. 49 and 52) which served, in the course of the tests, the purpose of the usual locomotive throttle. As the steam passing it was reduced from the pressure of the boiler to that of the exhaust pipe, it constituted an excel-

lent point of observation from which to secure data concerning the quality of the steam discharged. The addition of a gage and a thermometer made the whole arrangement serviceable as a calorimeter. Steam in excess of that required to produce the necessary draft conditions was discharged

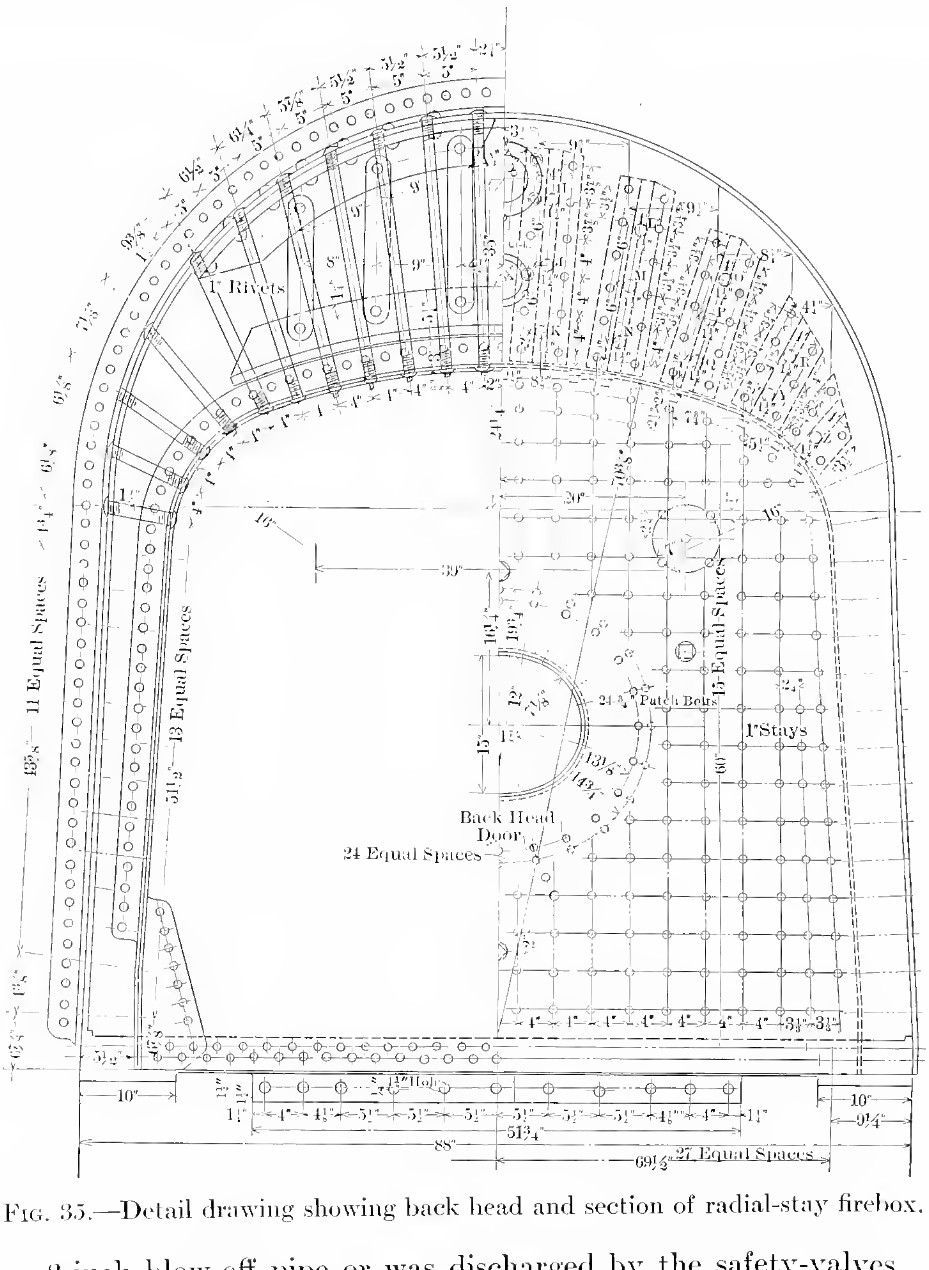


FIG. 35.—Detail drawing showing back head and section of radial-stay firebox.

from a 3-inch blow-off pipe or was discharged by the safety-valves. The boilers and connected steam-piping were well covered with asbestos covering. In all of these respects the equipment of the two boilers was identical.

48. The laboratory as described by the preceding paragraphs served for all the tests of Series A and B. In its operation, a staff of eight men were employed, acting under the immediate supervision of Mr. J. F. Butler.

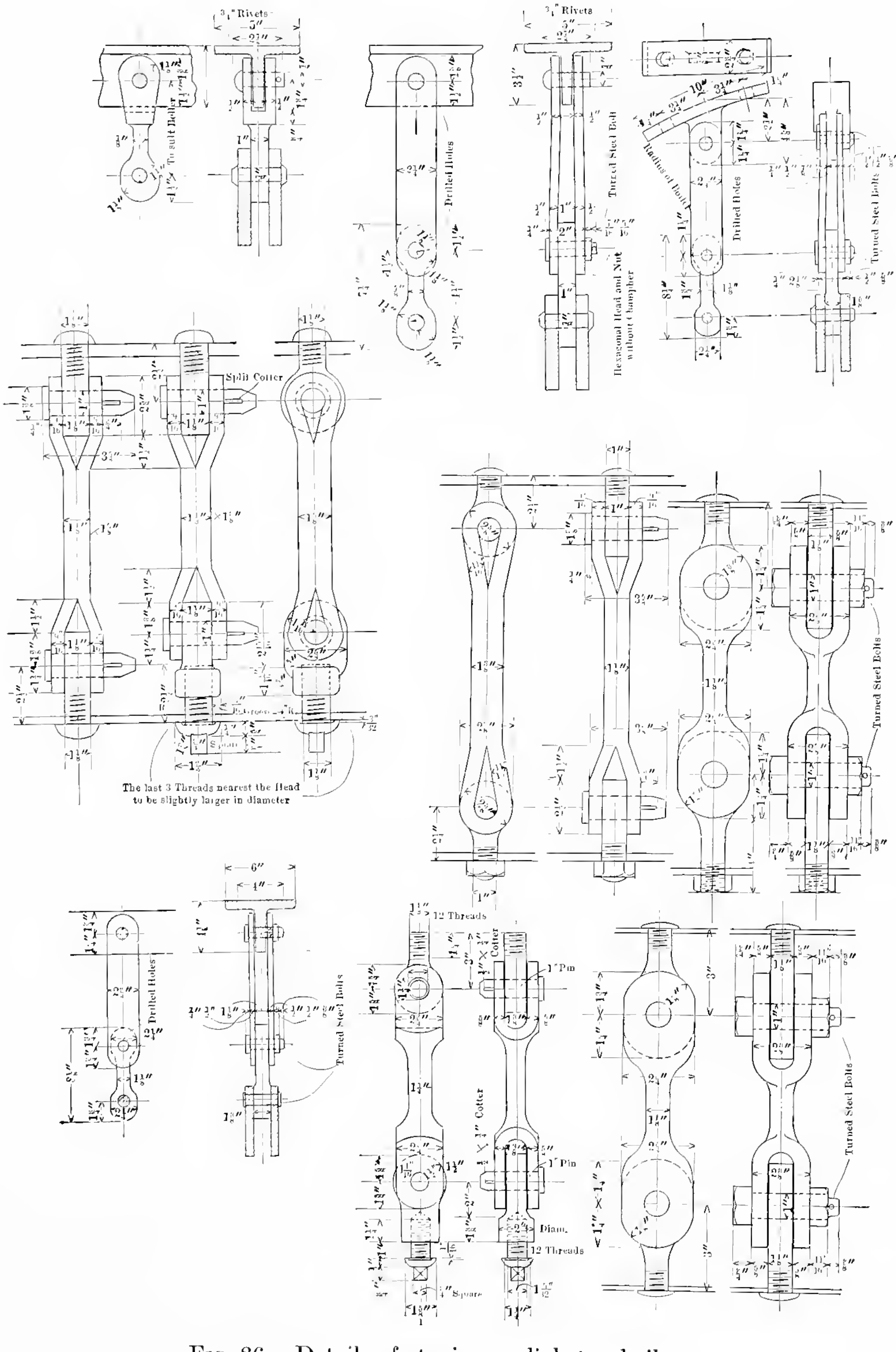


FIG. 36.—Details of staying, radial-stay boiler.

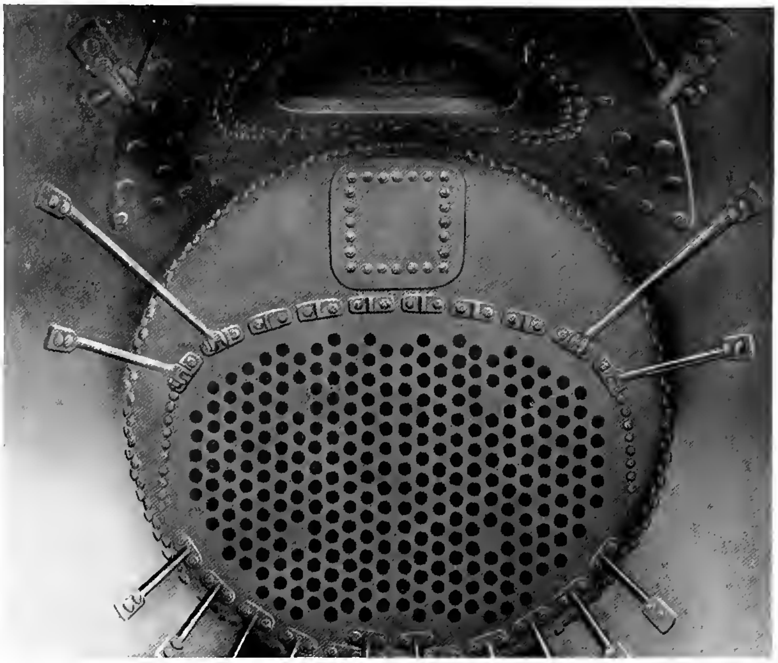


Fig. 37.—Photograph of partition in Jacobs-Shupert boiler from barrel of boiler. The partition separated the water space in two compartments for obtaining data in regard to relative capacity and efficiency of firebox and flue heating-surface. Tests Series A.

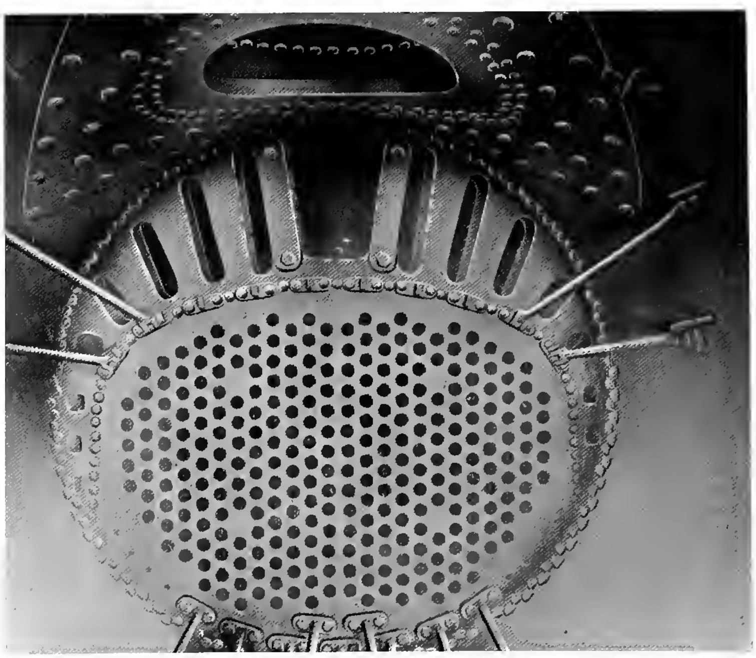


Fig. 38.—Back tube-sheet in Jacobs-Shupert boiler as used in Tests Series B, viewed from the barrel of the boiler. The partition was converted into this tube-sheet by cutting openings with the oxyacetylene flame.

49. While the tests of Series A and B were in progress, an investigation was conducted by Mr. George L. Fowler, concerning the movement of water within the boilers, the results of which are given in Chapter XII entitled "Some Facts with Reference to the Circulation of Water in Locomotive Boilers." At the conclusion of the tests of Series A and B, the

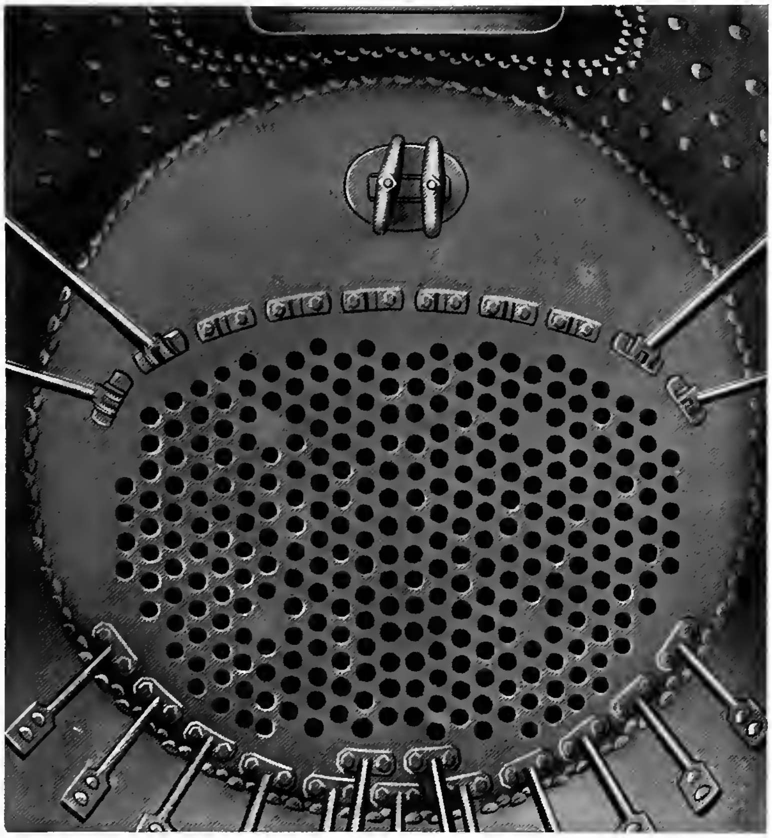


Fig. 39.—Photograph of partition in radial-stay boiler from the barrel of the boiler as used in Tests Series A. Firebox-sheets and wrapper-sheets were attached to partition by means of angle-irons.

boilers were dismantled, the covering upon them was removed, and they were transferred to the ground selected as a site for the low-water tests (Series C). An account of the re-equipment of the boilers for the low-water tests, a description of the tests and the results obtained from them constitute the subject of Chapter XI of this report.

VIII. The Relative Value of Firebox Heating Surface and of Tube Heating Surface as Determined by Tests of a Typical Jacobs-Shupert Boiler and a Typical Radial-Stay Boiler

50. Many years have passed since any effort has been made to establish by experimental processes the relative amount of heat absorbed by the firebox and by the tubes of a locomotive boiler. In the meantime, boilers have greatly increased in size and they have been so changed in their pro-

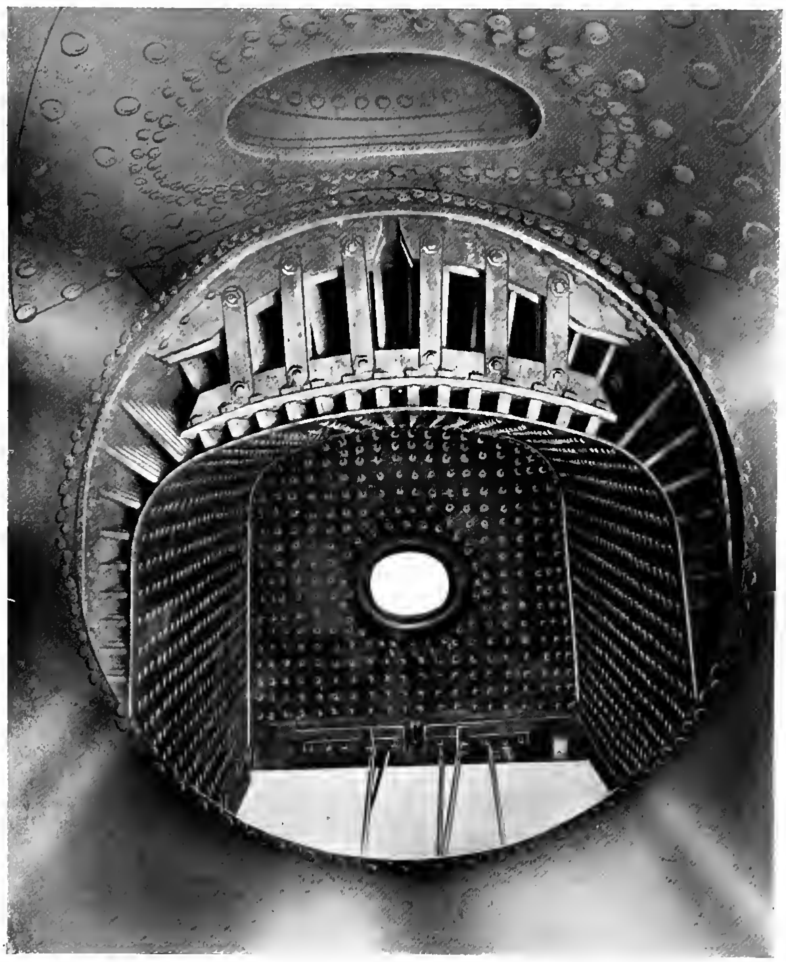


Fig. 40.—View in radial-stay boiler from barrel looking toward door-sheet after partition had been removed following conclusion of Tests Series A. A regular flue-sheet was applied for Tests Series B.

portion that no measure of a quarter of a century ago can now be accepted as applying to present-day practice. With the hope of making a contribution which would be of interest to the engineering profession, it was early arranged that the tests to be undertaken by the Jacobs-Shupert United States Firebox Company should include such a determination. In carry-

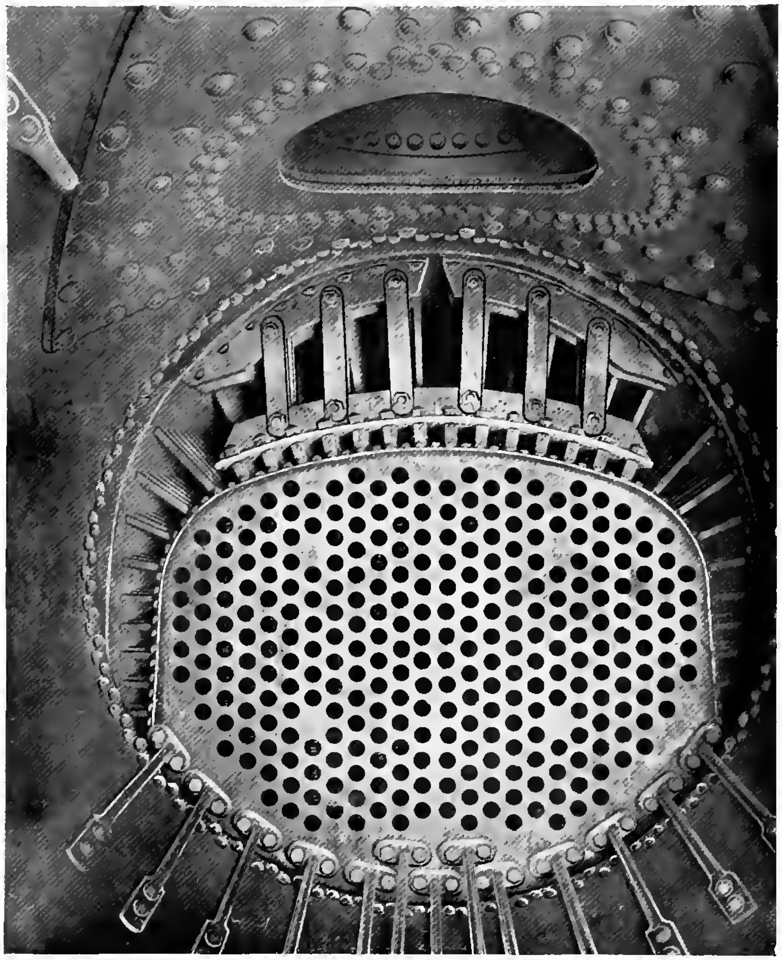


FIG. 41.—Photograph in radial-stay boiler showing flue-sheet and staying of firebox previous to start of Tests Series B.

ing out this purpose, both the Jacobs-Shupert boiler and the radial-stay boiler as initially constructed were partitioned off by an extension of the tube-sheet to the outside shell of the boiler. This partition separated the interior of the boiler into two compartments. The compartments were connected only through the medium of the steam piping, the arrangement of which was similar to that of two boilers connected to a common steam header. In the process of testing, both compartments received heat from a single source; namely, the interior of the firebox, but each compartment was fed from a separate supply of weighed water, and its output of steam was dealt with as though it had been a separate boiler. The details of

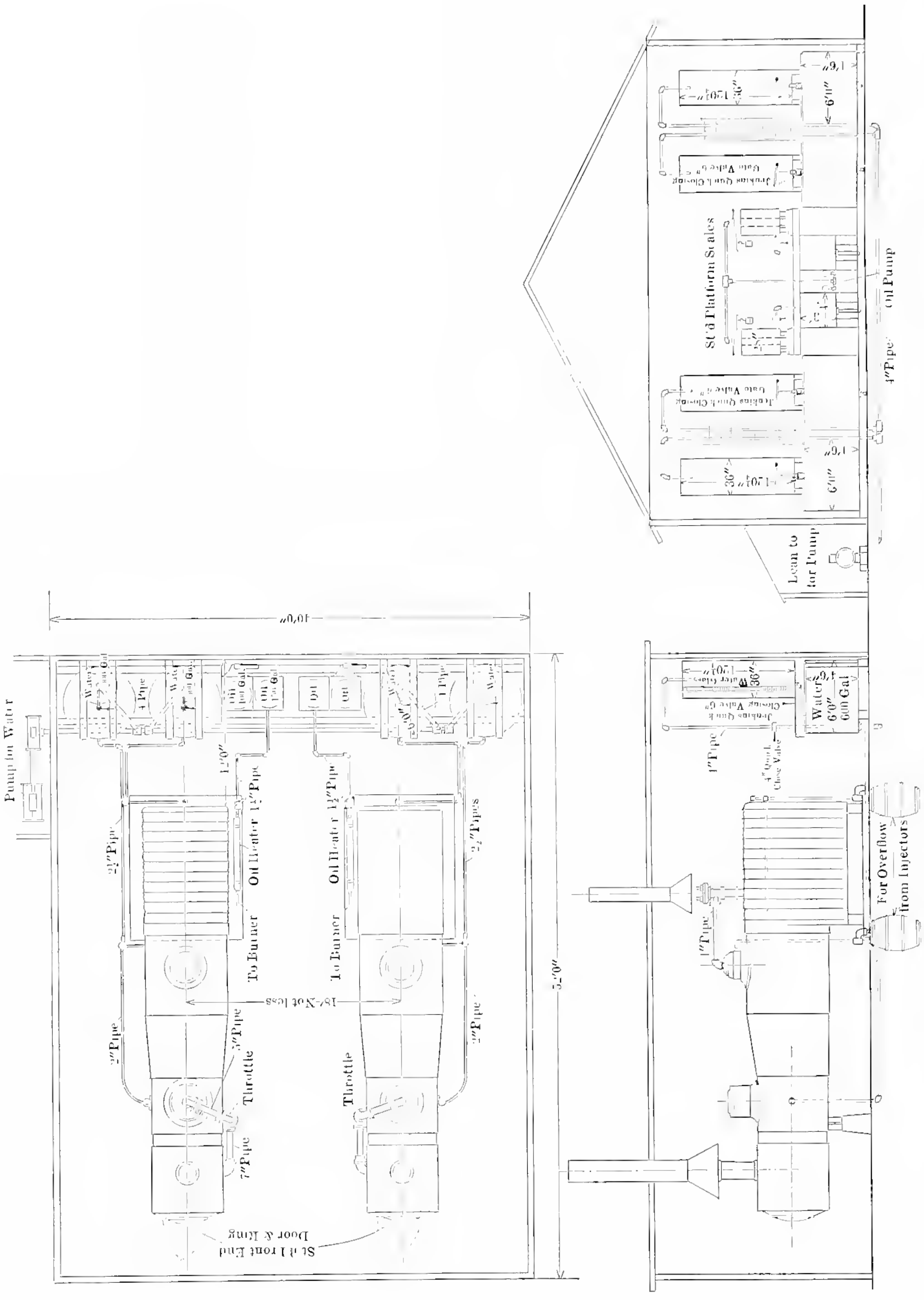


FIG. 42.—Plan, elevations and section of Testing Laboratory, showing boilers as arranged for the oil-fired tests. (Series A.)

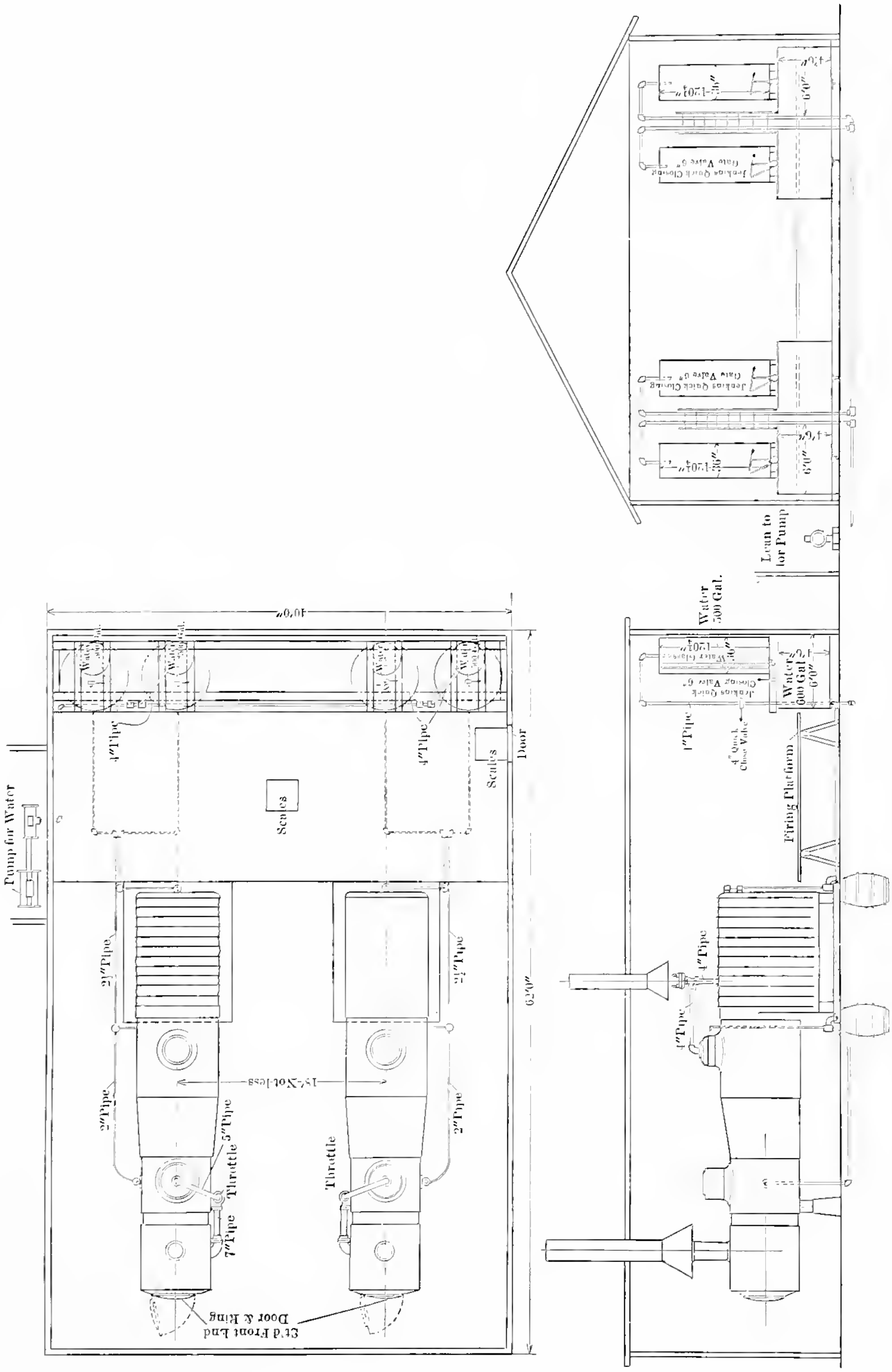


FIG. 43.—Plan, elevations and section of Testing Laboratory, showing boilers as arranged for coal-fired tests. (Series A and B.)

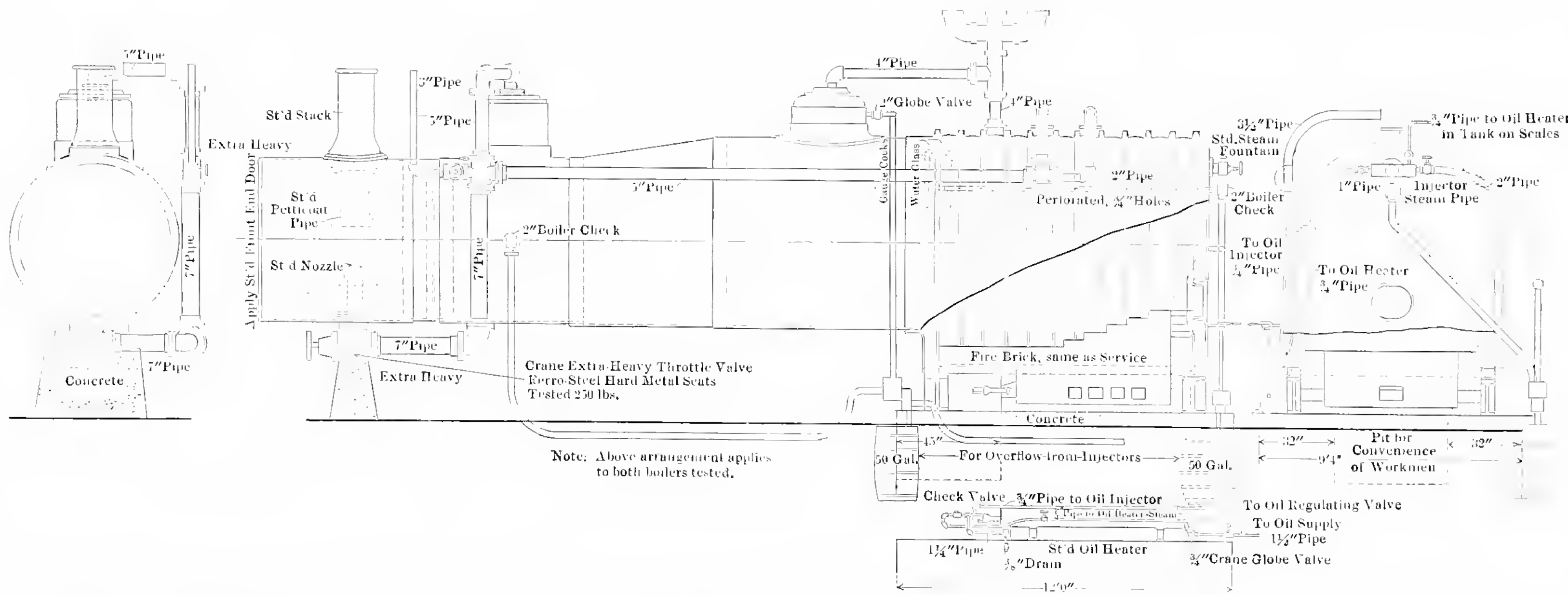


FIG. 44.—General elevation of Jacobs-Shupert boiler, showing piping and other arrangements for testing. The equipment of the radial-stay boiler was identical with that shown.

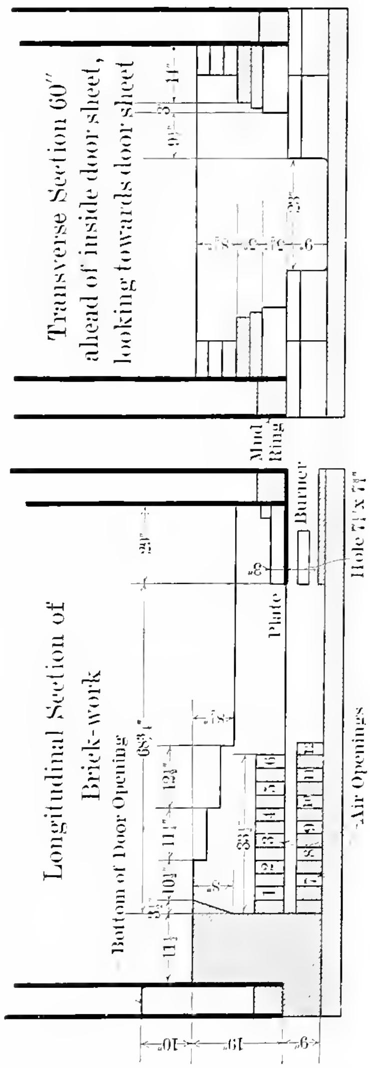


Fig. 45.—Arrangement of brickwork in fireboxes for tests when oil was used as fuel.

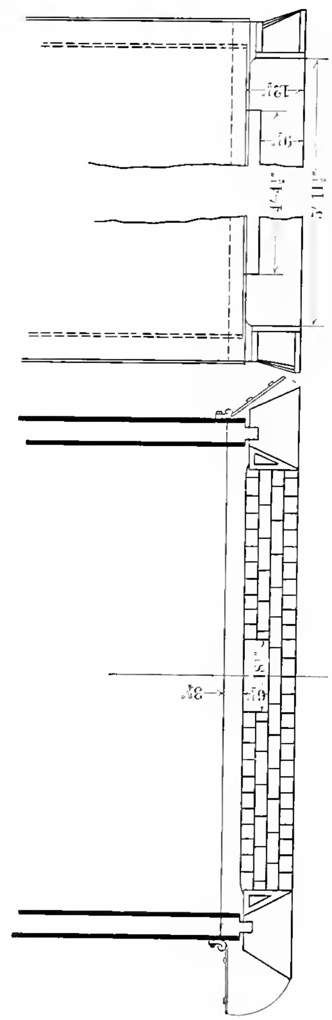


Fig. 46.—Arrangement of dampers and brickwork in fireboxes for tests when coal was used as fuel.

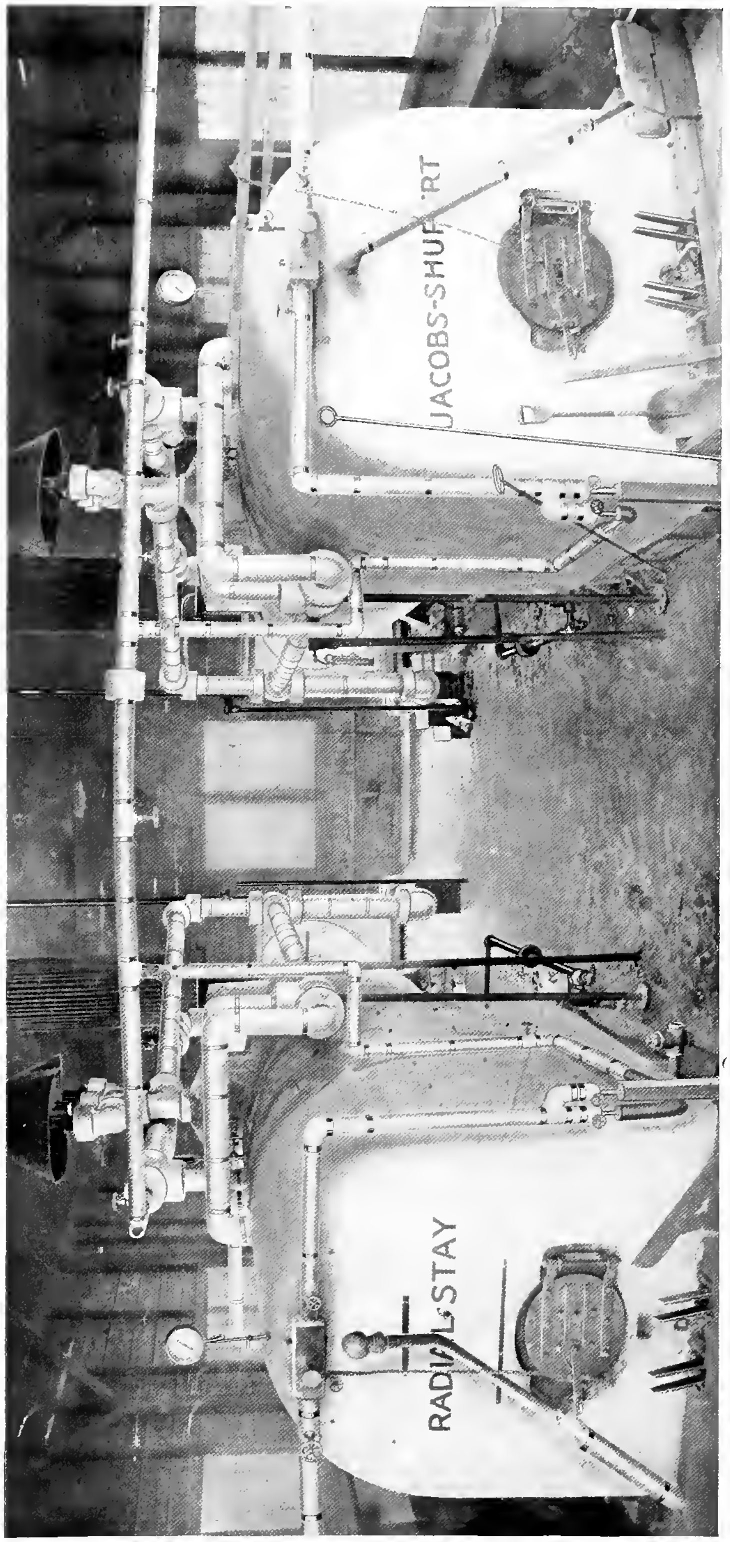


Fig. 47.—General view of interior of testing laboratory, showing location of boilers, hoods above stacks and safety-valves, arrangement of piping and test facilities.

the process may be perfectly apprehended by reference to the explanatory notes and the tables of Chapter XIII.

51. The location of the partition was such that the heat transmitted by the tube-sheet of the firebox was delivered to the barrel-end of the boilers, and the evaporation from this portion of the firebox was weighed in with that of the tubes. The observed data (Cols. 37 and 38) give the actual weighings of water fed to each portion of the boiler, and all items involving water evaporated, which follow in the tables, are deduced from these values, being based upon the observed results referred to the actual surface which was effective in bringing about

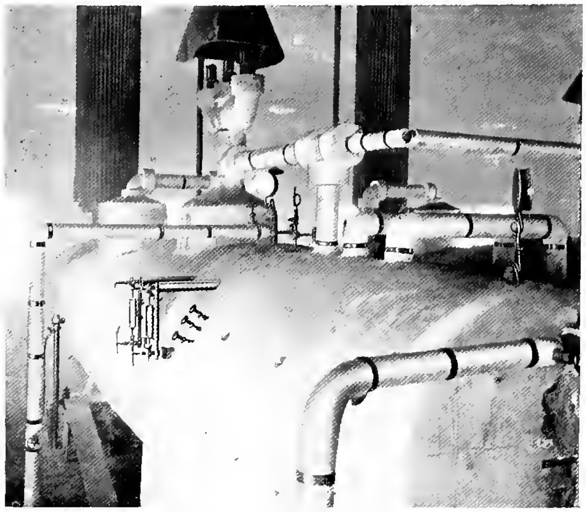


FIG. 48.—Photograph showing water-glasses and gage-cocks arranged for Tests Series A. These show water-levels in firebox and barrel when the same were separated by partition.

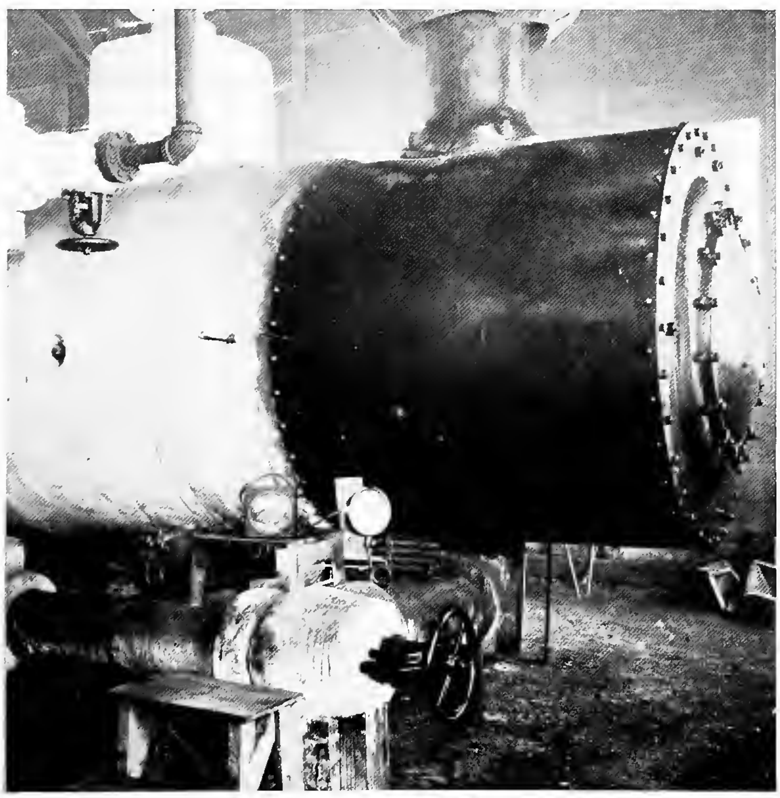


FIG. 49.—Photograph of forward end of test boiler showing main steam discharge pipe and controlling valve, the 3-inch relief pipe to atmosphere above it, and the electric pyrometer for indicating the temperature of smoke-box gases.

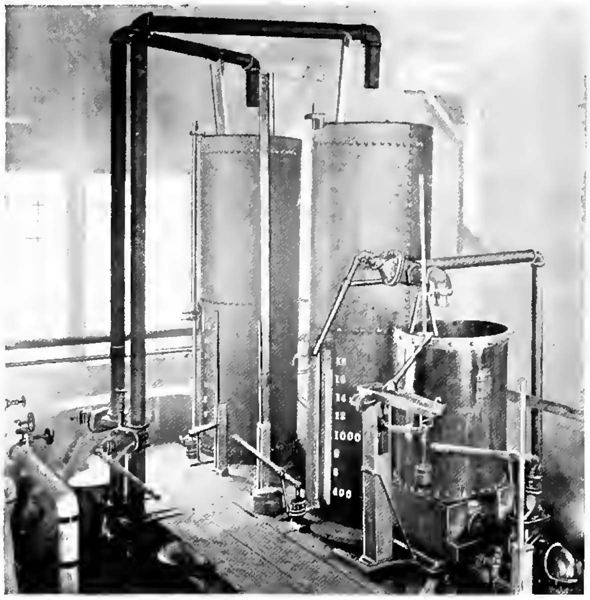


FIG. 50.—Two calibrated water tanks on left and fuel-oil weighing tank on right as arranged for Tests Series A. Water was supplied independently to the firebox and barrel by means of the separate water tanks.

FIG. 51.—Another view of fuel-oil weighing tank on platform and receiving tank below. After the oil was weighed it was discharged into the receiving tank from which it was fed directly to the burner by gravity.

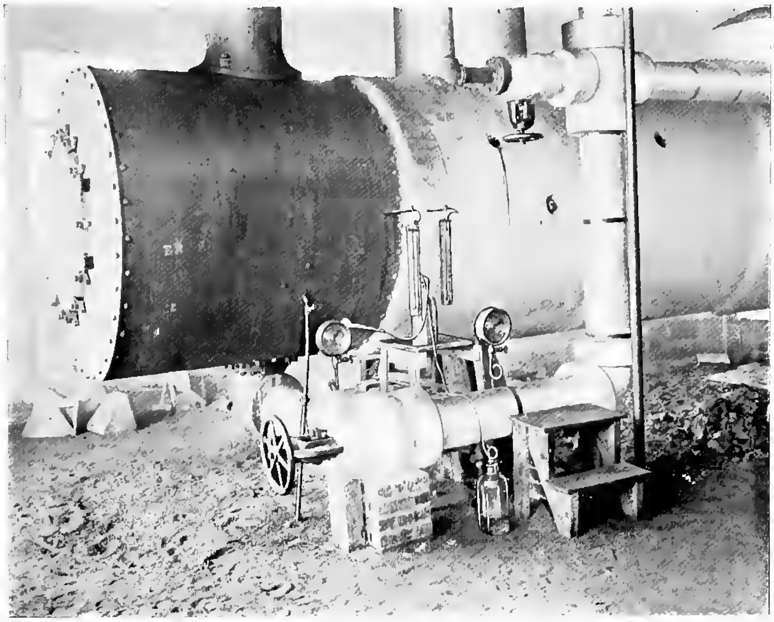


Fig. 52.—Photograph showing draft-gages in front and behind diaphragm, gas sampler for flue gases, and steam gages and thermometers in discharge pipe. The large valve served a double purpose, namely, that of regulating the draft, and with the apparatus behind it, as a throttling calorimeter. There were other calorimeters nearer the boiler.

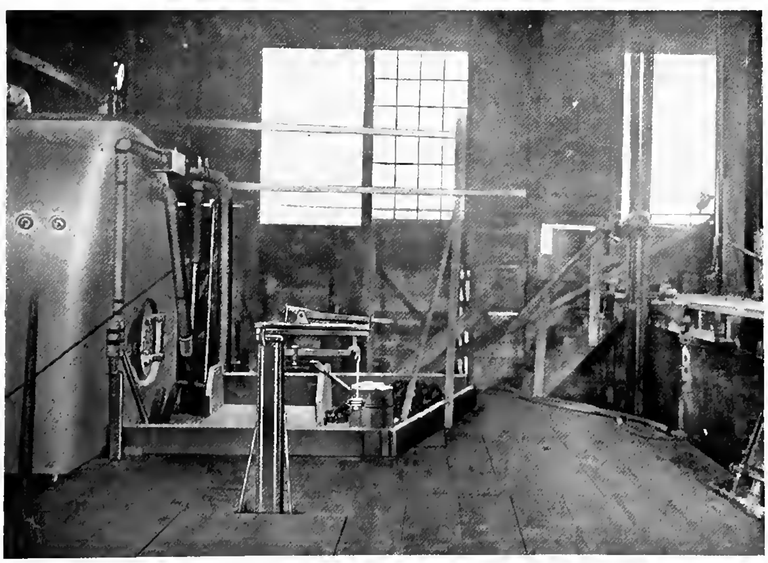


Fig. 53.—Photograph showing firing platform of one test boiler. Scales in foreground are for weighing ashes. Scales for coal are located near door of laboratory not visible in picture.

the result. The deduced values covering the firebox performance have been obtained by multiplying the evaporation actually obtained by the ratio of the total firebox surface to the firebox surface effective in producing vaporization in the firebox-end of this boiler. The small increment, which by this correction is added to the observed evaporation of the firebox, is in the deduced results, subtracted from the observed evaporation of the barrel. The effect of this correction is merely to credit to the firebox and debit to the barrel the heat transmitted by the back tube-sheet. These statements are, of course, applicable to both boilers.

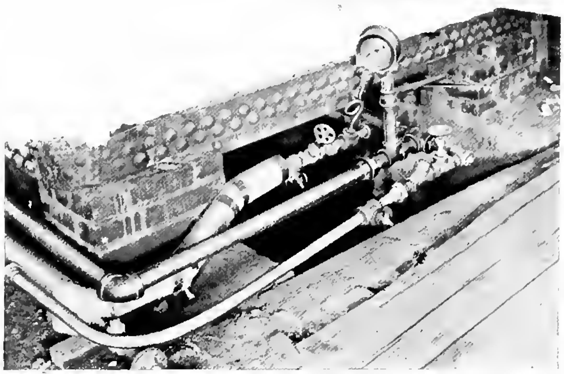


FIG. 54.—View at front of firebox, showing steam and oil pipes to fuel-oil burner. Gage shows pressure in steam line.

52. In the operation of the boilers constructed and equipped as described, a series of conditions appeared which, while unexpected, were interesting. It was found after starting fires under cold boilers that the firebox-end of the boiler would begin to make steam while the barrel remained comparatively cold. The steam thus generated by the firebox passed through the piping to the cooler steam space of the barrel, where much of it condensed. As a result, the water-level of the barrel would gradually rise and the water-level in the firebox-end would fall. The progress of these changes soon made it necessary to blow off water from the barrel, and to feed water to the firebox-end. This action operated greatly to prolong the process of getting the boiler into action. After the barrel began to make steam, both compartments performed normally as two boilers of a single battery, the quality of steam delivered from each being practically of the same value. It is obvious that the action described had nothing to do with the

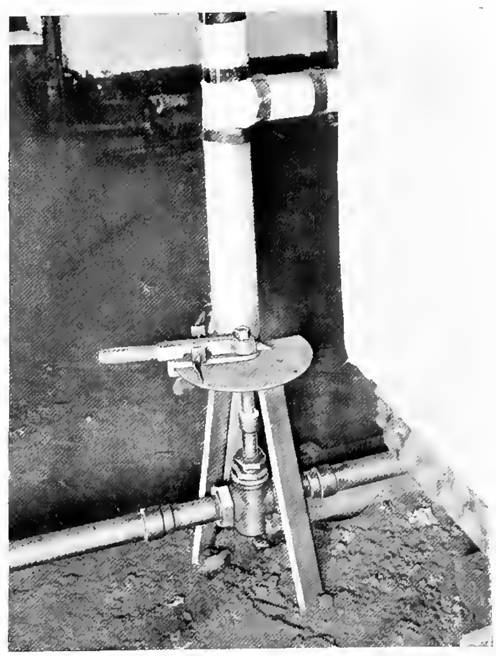


FIG. 55.—Valve for controlling fuel-oil supply to burner under boiler. A micrometer adjustment and calibration of valve provided a very delicate regulation of oil used during tests.

differences in the design of the two boilers, but was a result of the manner in which they were fitted up for the test in hand. The action occurred in connection with both boilers. It was completely overcome by adding a 2-inch emergency pipe connecting a washout hole in the bottom of the barrel with a washout hole in the water-leg of the firebox. This connection permitted, during the process of warming up, the firebox-end to be supplied with water from the barrel-end, and it established a channel for circulation which was found to be necessary to normal action. The pipe in question was provided with two valves and a drain between so that the circulation could be effectually stopped after both parts of the boiler were gotten into action.

53. The record of injector action for the two compartments, when the evaporation for the whole boiler equaled 25,000 pounds of water per hour, will be of interest as suggesting the constancy with which the conditions of the tests were maintained. It is as follows:

BARREL				FIREBOX			
Injector			Water Level Above Crown Sheet Inches	Injector			Water Level Above Crown Sheet Inches
On Clock Time	Off Clock Time	In Action Time in Seconds		On Clock Time	Off Clock Time	In Action Time in Seconds	
8–15	8–16	60	$5\frac{1}{4}$	8–16	8–17	40	6.0
8–18	8–19	65		8–20	8–21	35	
8–21	8–22	50		8–23	8–24	40	
8–24	8–25	50		8–25	8–26	40	
8–26	8–27	40		8–28	8–29	35	
8–29	8–30	55		8–31	8–32	30	
8–32	8–33	50		8–33	8–34	30	
8–35	8–36	50	$5\frac{3}{8}$	8–36	8–37	30	$5\frac{3}{8}$
8–37	8–38	55		8–38	8–39	30	
8–40	8–41	50		8–42	8–43	30	
8–43	8–44	55		8–45	8–46	30	
8–46	8–47	50		8–47	8–48	30	
8–48	8–49	55		8–49	8–50	30	
8–50	8–51	50		8–52	8–53	30	
8–53	8–54	55	5	8–55	8–56	30	5.0
8–56	8–57	50		8–58	8–59	30	
8–59	9–00	55		9–00	9–01	30	
9–01	9–02	50		9–03	9–04	30	
9–04	9–05	50		9–05	9–06	30	
9–07	9–08	55		9–08	9–09	30	
9–09	9–10	50		9–11	9–12	30	
9–12	9–13	55		9–14	9–15	30	
9–15	9–16	50	$4\frac{7}{8}$	9–17	9–18	30	$5\frac{1}{8}$
9–18	9–19	55		9–20	9–21	30	
9–21	9–22	50		9–24	9–25	30	
9–23	9–24	50		9–26	9–27	30	
9–25	9–26	55		9–28	9–29	30	
9–27	9–28	50		9–30	9–31	30	
9–29	9–30	55		9–34	9–35	30	
....	..	..	$4\frac{7}{8}$	....	....	..	$5\frac{1}{8}$

54. The tests upon the partitioned boilers are referred to throughout this report as those of Series A. Nine tests were made with oil as fuel, five upon the Jacobs-Shupert boiler and four upon the radial-stay boiler. These were followed by twelve tests, during which coal was used as fuel,

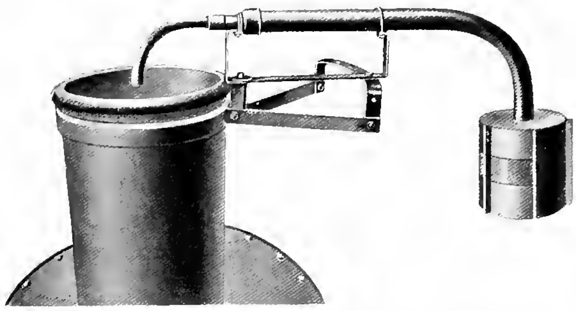


Fig. 56.—Cinder trap over stack of boiler. Samples taken in four positions.

six upon the Jacobs-Shupert boiler and six upon the radial-stay boiler. The results of all tests are given in detail by the tables of Chapter XIII. A summarized statement of the more significant facts developed is as follows:

Series A. Oil Fuel

55. Numerical values which are of especial interest are presented in Table 1, and a diagram showing the percentage of the total heat absorbed by the firebox as Fig. 57. The points plotted in this diagram include all results as obtained from both the Jacobs-Shupert boiler and the radial-stay boiler. Referring to Table 1, it will be seen that each pound of oil burned resulted in the evaporation of from 15.9 to 13.2 pounds of water, the amount diminishing as the rate of power is increased. The thermal efficiency of the Jacobs-Shupert boiler under low rates of power may exceed 80 per cent. and even under high rates of power it is above 70 per cent. It can be shown that when the Jacobs-Shupert boiler is made to evaporate 20,000 pounds of water an hour, it will generate 14.14 pounds of steam for each pound of oil burned. It can be shown also from data to be presented later in this chapter that at the same rate of power it will generate 8.3 pounds of steam for each pound of Dundon coal burned, so that a comparison of the results here presented, with others which are to follow, makes one pound of oil in locomotive service equal to 1.7 pounds of high-grade bituminous coal.

56. With reference to the distribution of work between the firebox and the tubes, Fig. 57 shows that the fraction of the total heat transmitted which is taken up by the firebox is greatest when the rate of power is low. Thus, when only 800 pounds of oil are being fired per hour, 54 per cent. of the total evaporation is from the firebox surface, whereas when 2,200

SERIES A—OIL FUEL

Table 1

DESIGNATION OF TEST	DRAFT IN FRONT OF DIAPHRAGM INCHES OF WATER	OIL PER HOUR pounds	EQUIVALENT EVAPORATION PER HOUR			EQUIVALENT EVAPORATION PER SQUARE FOOT OF HEATING SURFACE PER HOUR			PER CENT. OF TOTAL EVAPORATION IN FIREBOX	EQUIVALENT EVAPORATION PER POUND OF FUEL pounds	EFFICIENCY [OVER ALL] PER CENT. OF B. T. U. ABSORBED BY THE BOILER PER LB. OF FUEL FIRED
			FIREBOX pounds	BARREL pounds	TOTAL pounds	FIREBOX pounds	BARREL pounds	TOTAL pounds			
1	13	15	52	53	54	56	57	58	55	63	69
A-1-J	1.5	736	6,136	5,604	11,740	26.59	2.02	3.90	52.27	15.96	80.48
A-2-J	2.6	1,453	10,428	11,509	21,937	45.18	4.14	7.29	47.54	15.10	76.35
A-3-J	3.0	1,399	9,227	11,650	20,877	39.98	4.19	6.94	44.27	14.92	75.44
A-4-J	5.2	2,156	11,683	18,186	29,869	50.62	6.55	9.93	39.11	13.86	70.05
A-5-J	6.5	2,117	11,206	17,750	28,956	48.55	6.39	9.63	38.70	13.68	69.15
A-6-R	1.2	790	6,914	5,546	12,460	33.45	2.00	4.18	55.48	15.77	79.72
A-7-R	2.8	1,504	9,743	12,141	21,884	47.14	4.37	7.33	44.52	14.55	73.55
A-8-R	2.6	1,440	10,946	10,734	21,680	52.96	3.86	7.27	50.19	15.06	76.14
A-9-R	6.1	2,106	11,942	15,847	27,789	57.78	5.71	9.31	42.97	13.20	66.70

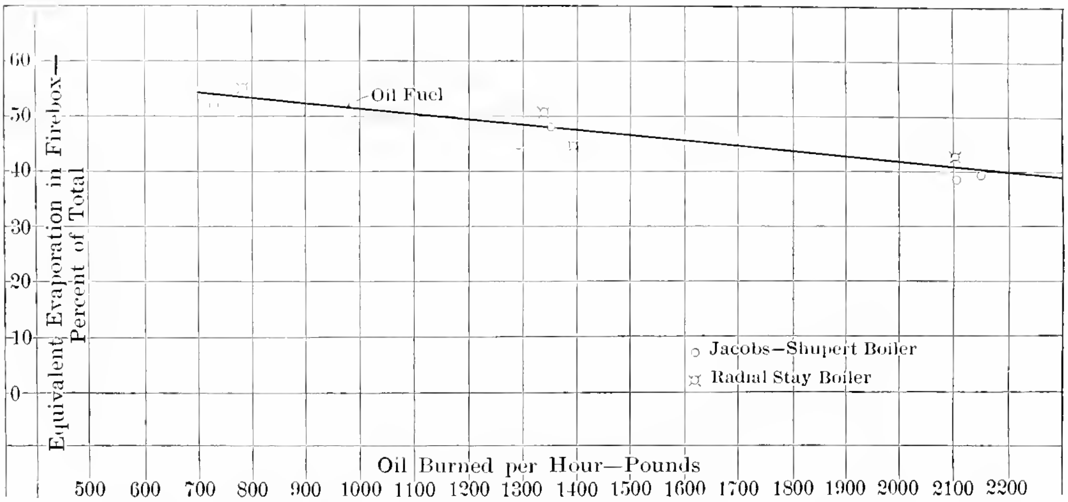


Fig. 57.—Ratio of evaporation in firebox to oil burned per hour. Test Series A—Oil Fuel.

pounds of oil are fired per hour, 40 per cent. of the total transmission is through the firebox. This statement shows that the proportion of the whole work done by the firebox is not only surprisingly large at its maximum, but that it continues to be large under all conditions of operation. Translating the facts presented by these values given into measures which are more readily recognized, and expressing them in round numbers, it may be said that when served with 2,200 pounds of oil per hour:

The Jacobs-Shupert boiler will evaporate 40,000 pounds of water per hour. Of this amount, 16,000 pounds will be evaporated by the firebox and 24,000 pounds by the barrel.

The whole boiler will develop 1,200 horse-power, of which amount nearly 500 horse-power will be developed by the firebox.

The average rate of evaporation per foot of heating-surface per hour for the whole boiler will be 9.78 pounds.

The average rate of evaporation per foot of heating-surface per hour for the firebox will be 49.59 pounds, and for the barrel 6.47 pounds.

The ratio of heat absorbed per foot of heating-surface by the firebox to that absorbed per foot of tube heating-surface is as 7.6 to 1.

57. While the tests show the efficiency of the boilers when fired with oil to be high, and while the results are very consistent, they can not be accepted as constituting a basis of comparison which admits of a high degree of refinement. This fact arises from difficulties encountered in the maintenance of a satisfactory fire. The burning of oil in large quantities within the firebox of a locomotive boiler presents a problem which has not yet been perfectly solved. In the case of the boilers experimented upon, the burner, the brickwork, and all other provisions affecting combustion were made to agree with the practice of large railway corporations having hundreds of locomotives oil-fired. The undersigned believes that the results obtained at the testing plant were probably as satisfactory as any which are obtained upon the road, but it was impossible in the mainte-

nance of the fire to prevent deposits of soot upon the heating-surface. The practice of thoroughly cleaning the heating-surfaces before starting fires, and of afterwards doing nothing to them during the progress of the test, resulted in abnormally high smoke-box temperatures and in the accumulation of considerable quantities of soot which was required to be removed at the end of the test. All results obtained under this practice were finally discarded. Later recourse was had to sanding the tubes, a practice common on railroads. At regular intervals during the progress of the test a scoopful of sharp sand was carefully distributed through the door into various portions of the furnace in such a manner that the particles would be taken up by the draft and carried through the tubes, cleaning them as by a sand-blast process. While this practice gave cleaner tubes, it did not clean the firebox, and an attempt was made to reach this portion of the heating-surface by using an air-blast with sand. As a result of these efforts systematically applied, the results obtained are fairly consistent, but since it is known that the performance of the boiler was more or less affected by the presence of soot, and since it can never be certain that the extent of this defect was constant for all the tests made of record, the results can not be accepted as constituting a measure of the relative performance of the two fireboxes, which is satisfactory from a scientific point of view. For this reason, also, no attempt has been made to elaborate, through a complete heat balance, the computations of the oil-fired tests.

Tests of Series A with Coal

58. The more essential facts developed by these tests are set forth in Table 2. This table includes the results of twelve tests, six upon the Jacobs-Shupert boiler and six upon the radial-stay boiler. For each boiler, two tests were made with Scalp-Level coal and four with Dundon coal. The Scalp-Level coal burns with a short flame. Its analysis (coal as fired) is as follows:

	Per cent.
Fixed carbon	75.90
Volatile matter	16.45
Moisture	2.15
Ash	3.50

The Dundon coal is a long-flame gas coal. Its analysis (coal as fired) is as follows:

	Per cent.
Fixed carbon	49.54
Volatile matter	34.34
Moisture	3.38
Ash	12.74

59. The results show that under low rates of power either boiler will give an evaporation of more than 10 pounds of water per pound of coal. For the whole series of tests the evaporation is normally above 8 pounds

TESTS] SERIES A—COAL FUEL

Table 2

Designation of Test	Draft in Front of Diaphragm Inches of Water	Kind of Coal	Moisture Free Coal Fired per Hour pounds	Equivalent Evaporation per Hour: Firebox pounds	Equivalent Evaporation per Hour: Barrel pounds	Equivalent Evaporation per Hour: Total pounds	Equivalent Evaporation per Square Foot of Heating Surface per Hour: Firebox pounds	Equivalent Evaporation per Square Foot of Heating Surface per Hour: Barrel pounds	Equivalent Evaporation per Square Foot of Heating Surface per Hour: Total pounds	Per Cent. of Total Evaporation in Firebox	Equivalent Evaporation per Lb. of Moisture Free Coal as Fired pounds	Efficiency (Over All) Per Cent. of B. T. U. Absorbed by the Boiler per Lb. of Fuel Fired
1	13	16	21	52	53	54	56	57	58	55	64	69
A-101-J	1.2	Scalp Level	1,324	6,149	8,363	14,514	26.64	3.01	4.82	42.36	10.96	71.62
A-102-J	1.3	Dundon	1,622	6,944	7,306	14,250	30.09	2.63	4.74	48.74	8.79	62.01
A-103-J	4.4	Scalp Level	2,498	8,949	16,379	25,328	38.77	5.90	8.42	35.33	10.14	65.79
A-104-J	4.2	Dundon	2,990	9,826	15,853	25,679	42.57	5.71	8.54	38.27	8.59	67.39
A-105-J	7.3	Dundon	4,228	11,982	23,423	35,405	51.92	8.43	11.77	33.84	8.38	58.65
A-106-J	6.7	Dundon	4,392	12,043	22,340	34,383	52.18	8.04	11.43	35.03	7.83	55.12
A-107-R	1.5	Dundon	1,721	7,225	7,538	14,763	34.95	2.71	4.95	48.93	8.58	60.22
A-108-R	1.1	Scalp Level	1,434	6,383	8,620	15,003	30.88	3.10	5.03	42.54	10.46	68.65
A-109-R	3.4	Scalp Level	2,418	7,734	16,427	24,161	37.42	5.91	8.10	32.01	9.99	64.68
A-110-R	3.1	Dundon	2,835	9,848	14,589	24,437	47.64	5.25	8.19	40.30	8.62	60.51
A-111-R	7.7	Dundon	4,250	11,992	23,782	35,774	58.02	8.56	11.99	33.52	8.42	61.10
A-112-R	6.4	Dundon	4,138	11,009	23,544	34,553	53.26	8.48	11.58	31.86	8.35	60.09

of water per pound of coal. A comparison of the performance of the whole boiler when delivering a definite amount of power, shows that the thermal efficiency is from 8 to 10 per cent. less when coal is fired than when oil is used as fuel.

60. The percentage of the total heat absorbed by the boiler, which is taken up by the firebox when the fuel is coal, is shown diagrammatically by Fig. 58. The points plotted upon this diagram fall into two series of groups. The first located by double circles represents all results obtained with Dundon coal, both from the Jacobs-Shupert boiler and the radial-stay boiler. The second located by single circles represents results obtained with the Scalp-Level coal. Neither boiler was equipped with the brick arch during these tests. It is interesting to note that the short-flame coal is at a distinct disadvantage as compared with the long-flame coal in giving up heat to the firebox. When Dundon coal is used as fuel, the percentage

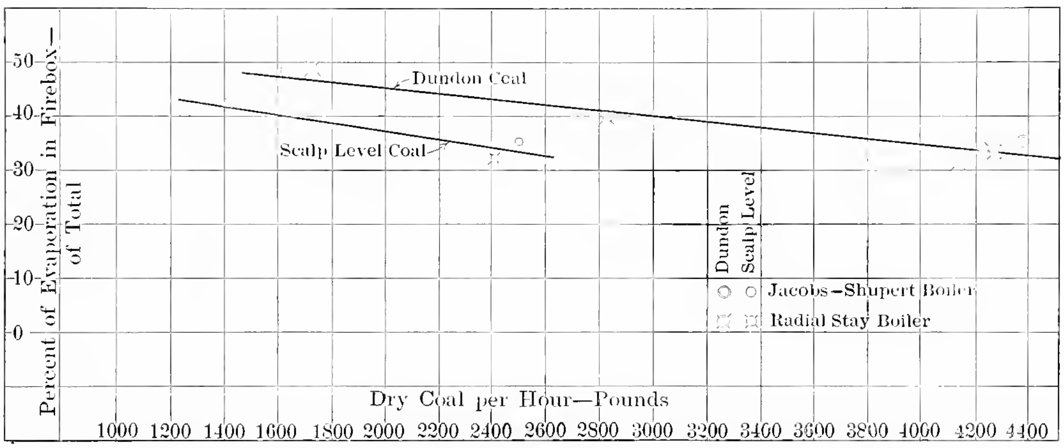


FIG. 58.—Ratio of evaporation in firebox to coal burned per hour. Tests Series A—Coal Fuel.

of the total heat absorbed by the firebox varies from a little less than 50 to a little more than 30, depending upon the rate of power, the percentage diminishing as the power is increased. When Scalp-Level coal is used, the percentage is about 8 less than when Dundon coal is used.

61. If we assume the Jacobs-Shupert boiler to be evaporating 20,000 pounds of water per hour, the percentage of the total heat absorbed by the boiler which is taken up by the firebox, is as follows:

	Per cent.
When oil is used as fuel	42
When long-flame bituminous coal is used as fuel	42
When short-flame coal is used as fuel	35

This suggests the possibility of the existence of some relation between the percentage of total heat which is absorbed by the firebox and the character of the fuel. For example, it may be that the substitution of anthracite for bituminous coal would operate to reduce the total work done by the

firebox below 35 per cent. The explanation is perhaps due to a changed condition in the tubes rather than in the firebox. It may be that the freer burning coal deposits less soot in the tubes and permits them to absorb a larger proportion of the total heat delivered.

62. It will be of interest to note that with Dundon coal when the rate of combustion equals 4,341 pounds per hour, which is near the highest reached in firing the partitioned boilers:

The Jacobs-Shupert boiler will evaporate 35,405 pounds of water per hour, of which amount 11,982 pounds will be evaporated from the firebox and 23,423 pounds from the tubes.

The whole boiler will develop 1,026 horse-power, of which amount 304 horse-power will be developed by the firebox.

The average rate of evaporation per foot of heating-surface per hour for the whole boiler will be 11.77 pounds.

The average rate of evaporation per foot of heating-surface per hour for the firebox will be 51.92 pounds, and for the barrel 8.43 pounds.

The rate of heat absorbed per foot of heating-surface by the firebox to that absorbed per foot of tube heating-surface is as 6.15 to 1.

A Comparison of the Performance of the Two Fireboxes

63. The Jacobs-Shupert firebox and the radial-stay firebox were designed and construeted to have the same over-all dimensions. The heating-surface of both fireboxes, as measured by their projected areas, is substantially the same and is equal to 206.7 feet. But the curved form of the seetions of the Jaeobs-Shupert firebox gives a developed area which is greater than that of the plain surfaee of the radial-stay firebox. The developed area of the surfaee of the Jacobs-Shupert firebox is 230.8 feet, an increase over the surface of the radial-stay firebox of 11 per eent. This increase in the heating-surface of the Jaeobs-Shupert firebox is an incident in the development of its design. The purpose of giving the sections of the firebox the shape they have is not primarily that greater heating-surface may be secured, but that a satisfactory structure may result. Nevertheless, a question as to the effeet of this increase in heating-surface upon the amount of heat absorbed by the firebox, is one of some importance, and its determination eonstitutes one of the questions for whieh the present series of tests was instituted. The results upon this point, as set forth in detail by Chapter XIII and as briefly reviewed in the short tables presented herewith as Tables 1 and 2, are not eonclusive. While results of individual tests may be selected which will show a considerably higher percentage of the total heat absorbed to have been taken up by the Jaeobs-Shupert firebox than by the radial-stay firebox, their effect is neutralized by the possibility of other eomparisons involving results believed to be equally reliable. The fact as developed by the results of 20 tests seems to indicate that the difference in absorbing capacity of the two fireboxes tested is not sufficient to be established by carefully conducted boiler tests. Heat transmitted by a locomotive firebox is ehiefly the

result of conduction and convection; radiation probably plays but a small part. Transmission by conduction is a function of differences in temperature. If in the case in hand, a plane in the water space above the crown-sheet is considered as receiving the heat and a parallel plane in the firebox below the crown-sheet as the source of heat supply, the amount of heat transmitted will theoretically be independent of the form of the metallic crown-sheet between. Again, the convection currents have a clear sweep over certain exposed portions of the firebox sections, but do not reach other portions which are between the sections. It is not unlikely that considerations such as these account for the results which have been obtained. These statements apply only to the fireboxes. The results which have been derived from the boilers as a whole are next described.

IX. Evaporative Tests of a Jacobs-Shupert Boiler and a Normal Radial-Stay Boiler

64. At the conclusion of the tests described in the previous chapter, the boilers were reconstructed to such extent as was necessary to secure the removal of the partitions, which in the previous work separated the firebox-end from the barrel. A statement of the means employed in bringing about this result will be found in Chapter VII. The reconstruction accomplished, there was available for the further work a normal Jacobs-Shupert boiler and a normal radial-stay boiler. Tests upon the normal boilers were first run using Scalp-Level coal as fuel and without the presence of an arch in the firebox. This series was followed by two tests in which Dundon coal, a long-flame gas coal, was used. After this, the brick arch was added to the firebox and the program of tests practically repeated. The details of the process may be perfectly apprehended and the results obtained easily understood by reference to the explanatory notes and the tables of Chapter XIII. The tabulated statement Table 3 presented herewith covers the more important results which were obtained from the entire series. A summary is as follows:

Results of Tests without the Brick Arch in Firebox

65. These are represented in Table 3 by tests 201 to 302, inclusive. The series includes five tests of the Jacobs-Shupert boiler and four tests of the radial-stay boiler when fired with Scalp-Level coal, and one test of each boiler when fired with Dundon coal. The efficiency of a locomotive boiler is highest when the power developed is least. For example, referring to the first test (201), it will be seen that when the Jacobs-Shupert boiler was fired with 1,315 pounds of moisture free coal per hour it—

(*a*) Evaporated 15,293 pounds of water per hour.
(*b*) Evaporated 5.08 pounds of water per square foot of heating-surface per hour.
(*c*) Evaporated 11.01 pounds of water per pound of coal.
(*d*) Developed 443 horse-power.
(*e*) Developed an overall efficiency of 71.86 per cent.
(*f*) Developed an efficiency, excluding the grate, of 79.75 per cent.

66. The precise effect produced by increasing the load upon a boiler is well shown by the values of the heat balance for the several tests run

Tests Series B—With and Without Arch

CONDENSED TABLE OF RESULTS

Table 3

DESIGNATION OF TEST	KIND OF COAL	MOISTURE FREE COAL PER HOUR pounds	MOISTURE FREE COAL PER SQ.FT. GRATE PER HR. pounds	EQUIVALENT EVAPORATION PER HOUR pounds	EQUIVALENT EVAPORATION PER SQ.FT. HEATING SURFACE PER HR. pounds	BOILER H. P. DEVELOPED	RATIO OF HEATING SURFACE TO H. P. DEVELOPED	EQUIVALENT EVAPORATION PER LB. OF COAL, MOISTURE FREE, FIRED	OVERALL EFFICIENCY	EFFICIENCY EXCLUDING GRATE
1	16	21	22	54	58	59	62	64	69	70
WITHOUT ARCH IN FIREBOX										
B-201-J	Scalp Level	1,389	24.45	15,293	5.08	443	6.8	11.01	71.86	79.75
B-202-J	" "	3,419	60.18	32,861	10.92	953	3.2	9.61	63.37	71.51
B-203-J	" "	4,467	78.63	39,964	13.28	1,158	2.6	8.95	58.29	63.96
B-204-J	" "	5,930	104.38	46,045	15.31	1,335	2.3	7.77	52.23	58.26
B-205-J	" "	6,314	111.14	48,070	15.98	1,393	2.2	7.61	50.41	55.36
B-206-R	" "	1,282	22.04	14,952	5.01	433	6.9	11.68	76.62	79.37
B-207-R	" "	3,051	52.46	29,108	9.75	844	3.5	9.54	62.26	66.41
B-208-R	" "	5,397	92.80	44,658	14.97	1,294	2.3	8.28	54.64	57.67
B-209-R	" "	5,427	93.31	42,404	14.21	1,229	2.4	7.81	52.25	54.39
B-301-J	Dundon	6,631	116.72	50,617	16.83	1,467	2.1	7.63	56.54	57.96
B-302-R	"	5,484	94.29	44,383	14.87	1,287	2.3	8.09	59.23	60.26
WITH ARCH IN FIREBOX										
B-401-J	Scalp Level	1,367	24.06	15,683	5.21	455	6.6	11.47	74.82	78.85
B-402-J	" "	2,656	50.27	30,484	10.13	884	3.4	10.67	69.79	75.50
B-403-J	" "	5,386	94.81	45,701	15.19	1,325	2.3	8.49	56.76	61.12
B-404-J	" "	5,887	103.63	51,759	17.21	1,500	2.0	8.79	57.90	61.27
B-405-R	" "	1,321	22.71	15,452	5.18	448	6.7	11.70	76.50	80.72
B-406-R	" "	2,926	50.31	29,953	10.04	868	3.4	10.24	67.42	72.10
B-407-R	" "	5,069	87.16	44,788	15.01	1,298	2.3	8.84	58.87	62.43
B-501-J	Dundon	6,553	115.35	57,564	19.13	1,669	1.8	8.78	65.34	67.01

with Scalp-Level coal. For example, tests 201, 202, 204, and 205 represent in the order given an increased rate of power. A statement of conditions and results is as follows:

Test number	201	202	204	205
Pounds of coal fired per hour	1,389	3,419	5,930	16,314
Thermal units for each pound of coal:				
(*a*) Absorbed by water in boiler	10,687	9,327	7,532	7,388
(*b*) Lost by moisture in coal	48	34	37	33
(*c*) Lost by moisture in air	49	53	114	64
(*d*) Lost by hydrogen in coal	486	497	500	514
(*e*) Lost by smoke-box gases	1,979	2,731	3,992	4,675
(*f*) Lost by incomplete combustion	78			
(*g*) Lost by cinders passing up stack	153	851	1,078	1,012
(*h*) Lost by combustible in ash	1,187	679	291	185
(*i*) Lost by radiation and unaccounted for	205	547	881	783
Total B. T. U. per pound of coal	14,872	14,719	14,425	14,654

By comparing the values in the horizontal lines, the changes resulting from changes in the rate of power may be seen. First, it will be observed that the number of thermal units absorbed by the water in the boiler becomes smaller with each succeeding test. The loss thus sustained is accounted for by the increased amount of heat which goes off with the smoke-box gases and in the form of combustible material which passes out of the stack as cinders.

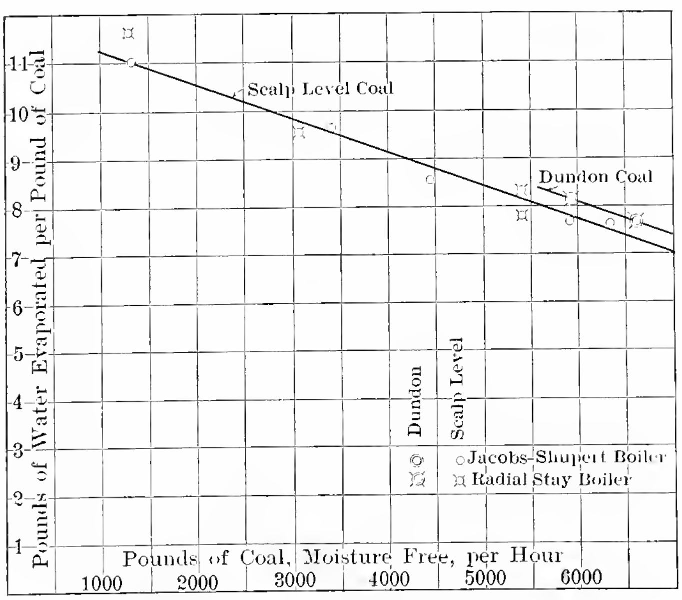


FIG. 59.—Water evaporated per pound of coal. Tests Series B. Without arch.

67. The evaporative performance of the boilers in terms of pounds of coal fired per hour is shown by Fig. 59. In this figure the double circles represent tests with Dundon coal and the single circles tests with Scalp-Level coal. Tests upon the Jacobs-Shupert boiler are indicated by the plain circles, while the tests on the radial-stay boiler are indicated by combined circles and crosses. The diagram represents all results obtained. Tests 301 and 302 were run with Dundon coal, all others with Scalp-Level coal. The long straight line represents the tests of the Jacobs-Shupert boiler when

using Scalp-Level coal, with a maximum error which is less than 3 per cent. and an average error which is less than one per cent. It will be seen that the line also represents fairly well the results obtained from the radial-stay boiler, which are marked by crosses. Dundon coal gives a higher evaporation than Scalp-Level coal. A parallel line is drawn through the two points representing the results obtained from the two boilers when fired with Dundon coal.

Results with a Brick Arch in the Firebox

68. Upon the completion of tests 201 to 302, inclusive, described in the preceding paragraphs, both boilers were equipped with firebox arches supplied and installed by the American Arch Company. Thus equipped, tests 401 to 501, inclusive, were run. A detailed description of the arches, together with a discussion of their effect upon boiler efficiency, is reserved for another place (Chapter X). The present purpose is to consider the results in their relation to the two boilers tested.

69. A summarized statement of the actual values appears in Table 3 and the comparative performance of the two boilers is set forth by Fig. 60. In the latter figure, the long straight line is drawn to represent as nearly as possible the points shown by circles, which are those of the Jacobs-Shupert boiler when fired with Scalp-Level coal. It will be seen that the line also represents fairly well the points located by crosses, which indicate results obtained from the radial-stay boiler. The crosses fall lower than the circles which determine the location of the line. Only one test representing Dundon coal is of record in this group, and this (501) is a test of the Jacobs-Shupert boiler at the highest rate of power developed during the series. In this test, the firing

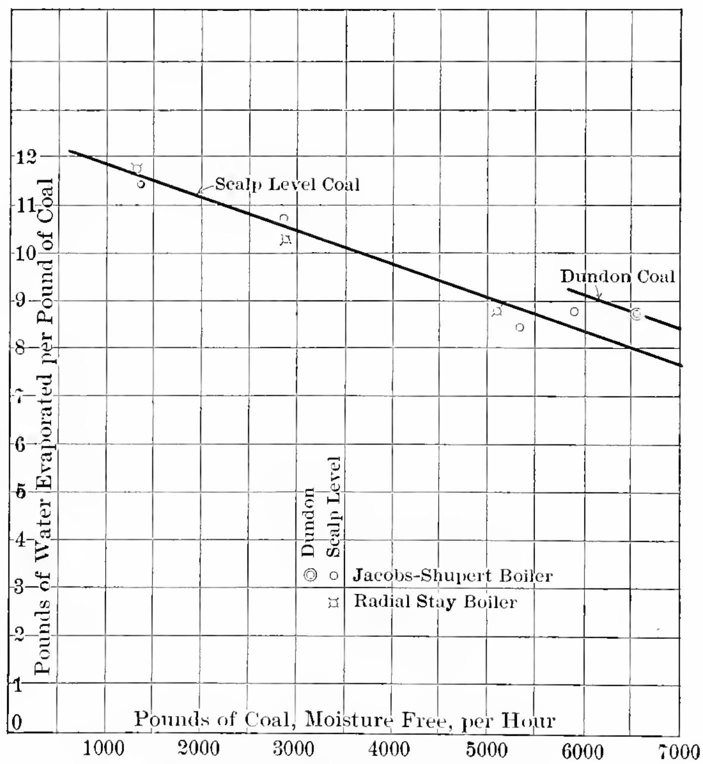


FIG. 60.—Water evaporated per pound of coal. Tests Series B. With arch.

was at the rate of 6,553 pounds of moisture free coal per hour. This rate of firing resulted in:

A rate of combustion equaling 119.38 pounds of coal per foot of grate per hour.

An evaporation of 57,564 pounds of water per hour, or the equivalent of 19.13 pounds of water per foot of heating-surface per hour.

The development of 1,669 boiler horse-power, or the equivalent of one boiler horse-power for each 1.8 foot of heating-surface.

An evaporation per pound of coal, notwithstanding the high rate of power developed, of 8.78 pounds of water.

The maintenance of an overall boiler efficiency of 65.34 per cent., and of the boiler, exclusive of the grate, of 67 per cent.

70. It is unusual for boilers to be driven to such rates of power. At the Purdue locomotive testing plant, as a result of its first fifteen years of operation, the highest rate of evaporation made of record was 14.45 pounds of water per foot of heating-surface per hour, obtained August 7, 1905, by the use of Youghiogheny coal. At about the same time the report of the Pennsylvania Railroad Company of the St. Louis tests was issued, by which it appeared that the New York Central locomotive No. 3000 had, while on the testing plant, been forced to a rate of 16.34 pounds per foot of heating-surface per hour, which was the maximum for that celebrated series of tests. It is in comparison with these record-breaking performances that the rate of 19.13 pounds obtained for the Jacobs-Shupert boiler at Coatesville is to be considered. So far as the undersigned is informed, it represents the highest rate of power to which any locomotive boiler has been driven.

71. The conclusion to be drawn from the tests of Series B concern evaporative efficiency and capacity. The results show that the Jacobs-Shupert boiler and the radial-stay boiler, under all the various conditions of the tests, operate at practically the same efficiency. There are indications that under very high rates of power the Jacobs-Shupert boiler has some slight advantage.

72. Two boilers of the same efficiency will generate equal amounts of steam for equal quantities of fuel consumed. Relative steaming capacity is in the case of such boilers a matter of relative coal-burning capacity. The superior strength of its firebox allows the Jacobs-Shupert boiler to be fired to very high limits of power without injury. Its strength thus becomes an indirect factor in extending its capacity. In this respect, the capacity of the Jacobs-Shupert boiler excels that of the radial-stay boiler.

X. The Brick Arch as a Factor in Boiler Performance

73. The tests of Series B afford an excellent basis from which to determine the value of a brick arch in a locomotive firebox. Some of these tests, Nos. 201 to 302, inclusive, were run with no arch; the others, Nos. 401 to 501, inclusive, were run with an arch. They involve both the Jacobs-Shupert boiler and the radial-stay boiler. Scalp-Level coal was used for some of these tests and Dundon coal for the others.

74. The arches used in these tests were, as previously noted, supplied

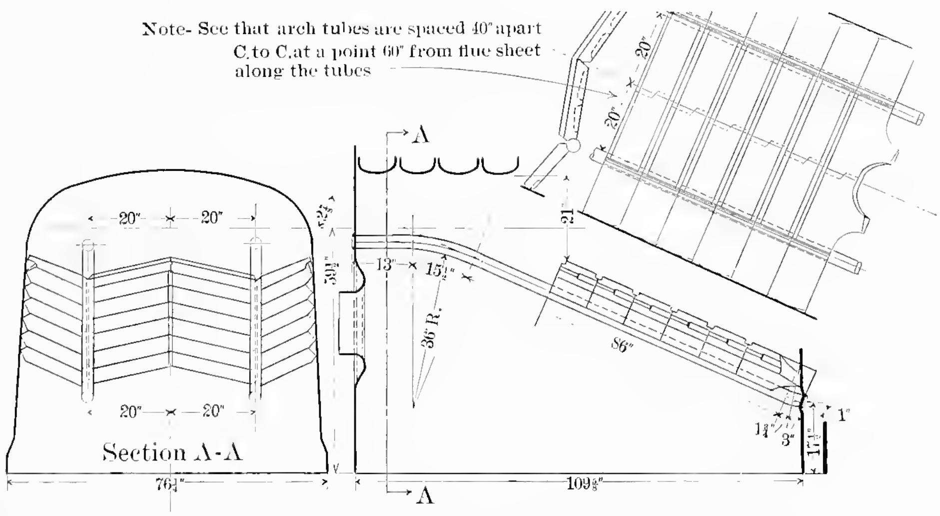


Fig. 61.—General drawing of brick arch as applied to Jacobs-Shupert firebox. Tests Series B.

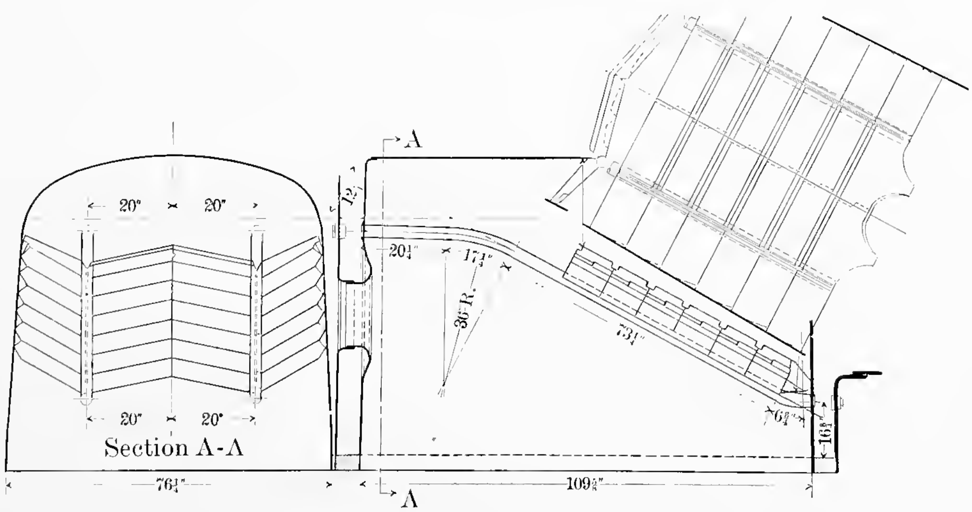


Fig. 62.—General drawing of brick arch as applied to radial-stay firebox. Tests Series B.

and installed by the American Arch Company. They were substantially the same for both boilers, but the curvature of the firebox sections of the Jacobs-Shupert boiler made necessary some slight differences in design. The arch as installed in the Jacobs-Shupert boiler is shown by Fig. 61, and as installed in the radial-stay boiler by Fig. 62.

75. The evaporative efficiency of the boilers with and without the arch is well shown by Fig. 63. In this figure the points shown as triangles

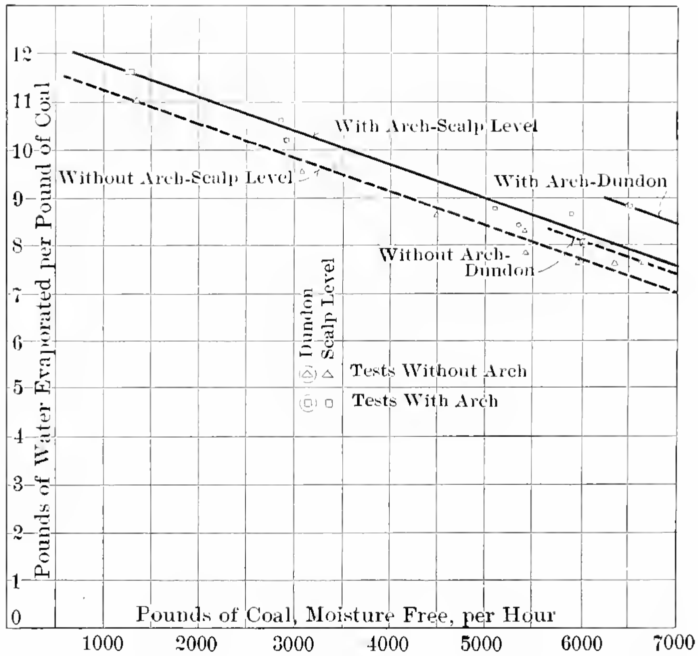


FIG. 63.—The effect of the brick arch in firebox on efficiency.

represent tests (Nos. 201 to 302, inclusive) without the arch. Nine of these tests were run with Scalp-Level coal, five on the Jacobs-Shupert boiler and four on the radial-stay boiler. The long dotted line drawn through this group of points may be accepted as representing the performance of both boilers without the arch fired with Scalp-Level coal. Similarly, the points located by squares represent results from both boilers with the arch. Six of these points represent tests with Scalp-Level coal, and the long full line may be accepted as fairly representing them. The addition of the arch raised the performance of these boilers from that represented by the dotted line to that represented by the full line, an increase of 0.6 of a pound in the amount of water evaporated per pound of coal. For example, assuming the boilers to have been fired with 6,500 pounds of Scalp-Level coal per hour, they will evaporate 7.35 pounds of water per pound of coal without the arch and 7.95 pounds of water per pound of coal with the arch, a gain of 8 per cent. Comparisons involving lower rates of combustion lead to smaller gains when these are expressed as a percentage of the evaporative efficiency. In the light of these experi-

ments, it is fair to say that the addition of an arch in the firebox of locomotives using Scalp-Level coal, results in increasing the efficiency from 5 to 8 per cent.

76. The points representing tests with Dundon coal are three in number. One representing the Jacobs-Shupert boiler and one the radial-stay boiler without the arch are shown on Fig. 63 as triangles enclosed in

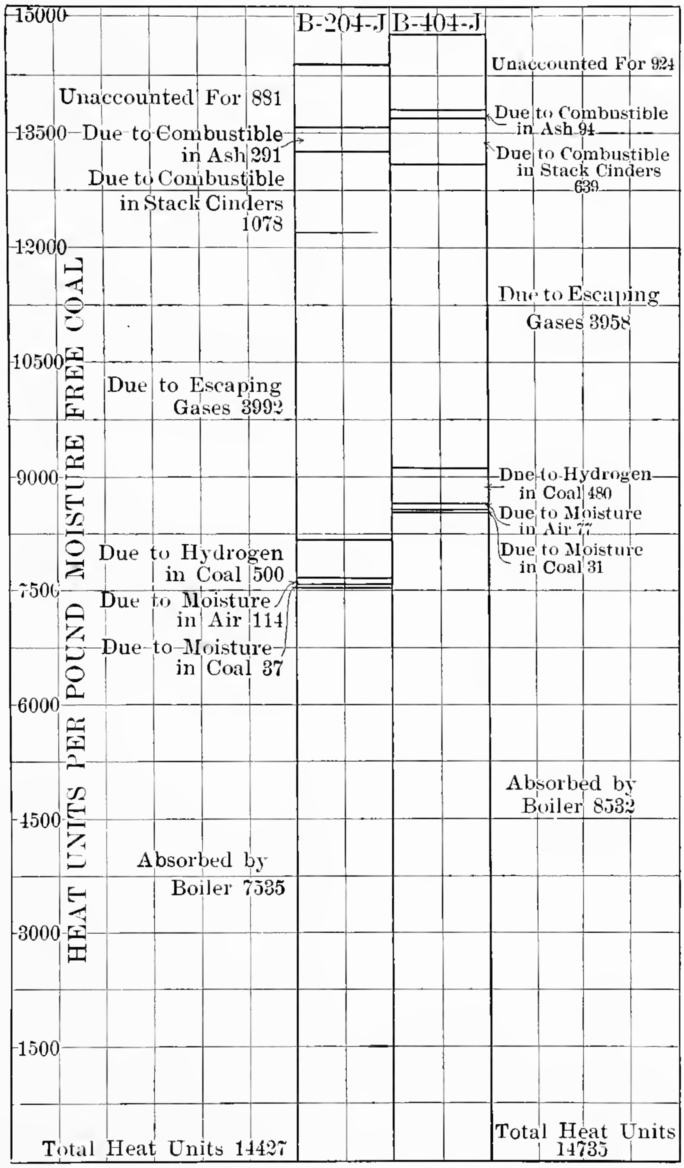


Fig. 64.—Comparison of heat balances of representative tests with and without arch.

circles, and one representing the Jacobs-Shupert boiler with the arch as a square enclosed in a circle. A short dotted line is drawn through the two points representing the two tests without the arch, and a short full line through the one point representing the test with the arch. The difference in the location of these lines measures the effect produced by the

arch. It represents an evaporation of one pound of water. Thus, when 6,500 pounds of Dundon coal are fired per hour, the boilers without the arch will evaporate 7.7 pounds of water per pound of coal, and with the arch, they will evaporate 8.7 pounds of water per pound of coal. This means that with Dundon coal the addition of the arch resulted in increasing the evaporative efficiency to the amount of 12 per cent.

77. The results of the heat analysis for two tests at substantially the same rate of power, one with the arch and one without it, are presented as Fig. 64.

78. The difference in the effect produced by the arch in connection with the two grades of coal is doubtless to be found in differences in the manner in which the coal burns. The Scalp-Level coal has only half the volatile matter of the Dundon coal. The benefits to be derived from the presence of an arch—the longer flame way, the better mixing of gases, and the conserving of high furnace temperature—are all matters which affect its combustion favorably, but the long-flame Dundon coal being in greater need of these advantages, naturally profited most by the presence of the arch.

XI. Low-Water Tests and Their Results

79. One of the principal advantages claimed for the Jacobs-Shupert boiler is that of increased safety. This claim has been based upon the fact that its firebox is made up of comparatively small sections, that the rivets joining the sections are entirely in the water space of the boiler, where even under low-water conditions they can not be exposed to the direct action of the heat, and that there are no stays in side-sheets or crown ending in the firebox. If low water occurs and the crown-sheet becomes overheated, the parts most affected are the curved portions making up the center of the sections, that is, the portions of the plates most

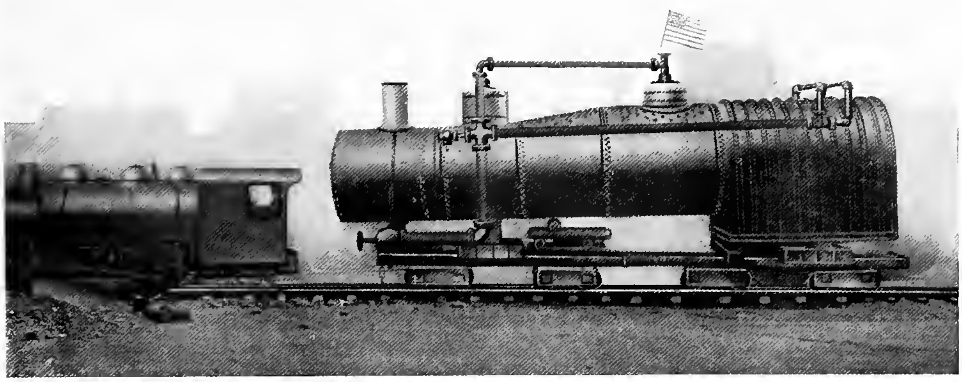


Fig. 65.—The Jacobs-Shupert boiler on the way to low-water testing grounds over the industrial tracks of the Lukens Iron & Steel Company. Note its size as compared with that of the boiler of the mill locomotive.

remote from the joints. The excessive heating, therefore, comes at a point which, by the design of the boiler, is best able to withstand it. It is, of course, entirely conceivable that even under these conditions the overheating may proceed to a point which will result in a failure of the sheet, but it has been claimed that even in such an event, a single section only will fail, that the plate will pocket and blow out through a comparatively small opening, and that the effect of the failure will be entirely local. These assumptions, if true, make the Jacobs-Shupert boiler a safety-boiler in the same sense that the modern water-tube boiler, so much used in stationary service, is a safety-boiler. If the action described actually takes place, there can be no explosions of a Jacobs-Shupert boiler such as occur in the case of a radial-stay boiler when the crown-sheet comes down. The confidence with which the claims for safety were put forth had been greatly strengthened by the results of a test of a large Jacobs-Shupert

boiler which was made at Topeka, Kansas, in the fall of 1910. These tests were most carefully conducted by Mr. H. B. MacFarland, and the results as reported by him completely sustain the assumption above stated. But notwithstanding the confirmatory evidence thus supplied, the officers of the Jacobs-Shupert company early expressed the desire that such tests be included in the series to be conducted by the undersigned,

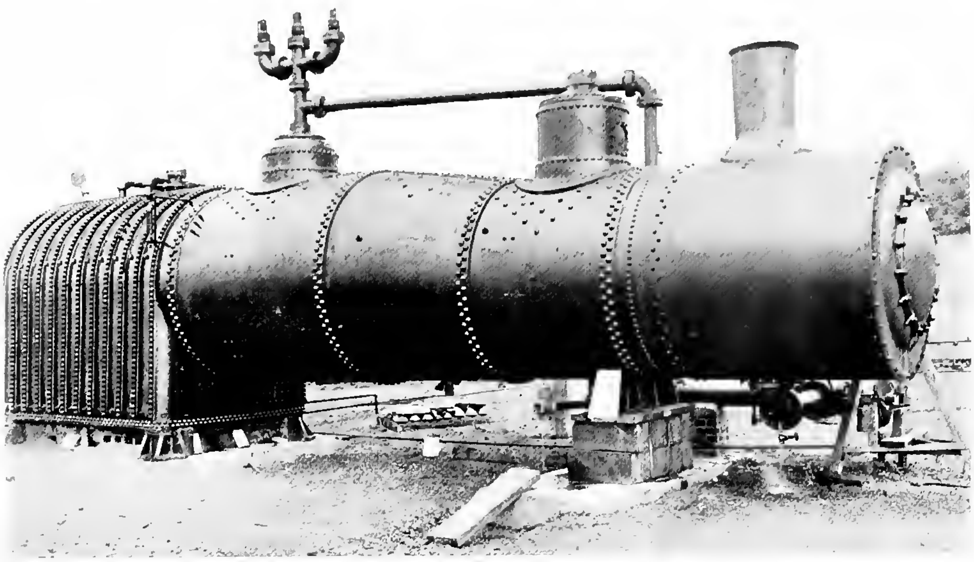


FIG. 66.—Setting of Jacobs-Shupert boiler for low-water test. View shows concrete piers and the substantial supports under the boiler.

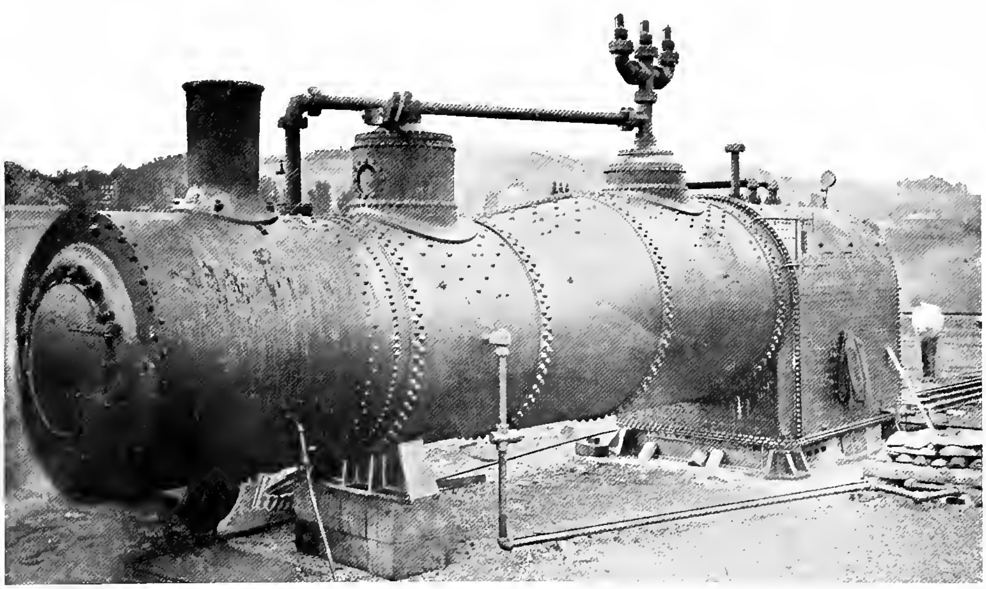


FIG. 67.—Setting of radial-stay boiler for low-water test. View shows the substantial concrete piers and supports identical to those under the Jacobs-Shupert boiler.

Fig. 68.—General view of testing ground, showing location of boilers with reference to each other, the shelter for the operating staff, the elevated fuel-oil tank, and the large display board for indicating to guests in the pavilion the water-levels and steam pressures during tests.

and these were, as a consequence, specified in the original outline. This provided that at the conclusion of the evaporative tests, the results of which have already been presented, both the Jacobs-Shupert boiler and the radial-stay boiler should be tested to complete failure under low-water conditions if that should be practicable.

80. The boilers have already been described (Chapter VII). Both were of the same general dimensions, and both were designed for a working pressure of 225 pounds. As has been previously stated, the firebox-end of the Jacobs-Shupert boiler was selected at random from a number of similar fireboxes under construction at Coatesville on the order of a railroad company. There was nothing special about it. It was, however, fitted up under the scrutiny of a personal representative of the undersigned. It was no stronger or better than the others of the same lot.

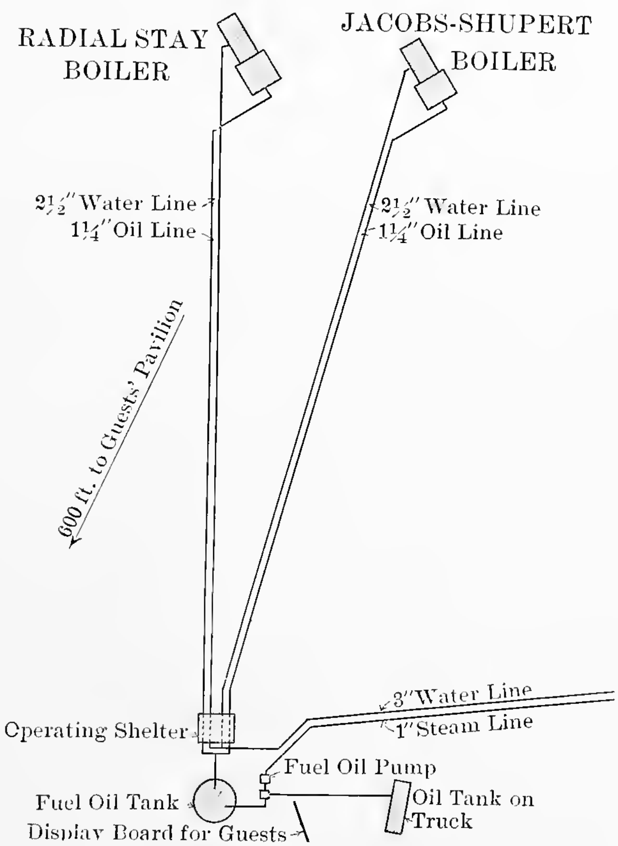


Fig. 69.—Ground plan of testing field.

FIG. 70.—The shelter for operating staff in low-water tests, consisting chiefly of a Jacobs-Shupert firebox behind an embankment of timber and dirt. Located about 200 feet from boiler.

81. The radial-stay boiler was constructed under the specifications of the Santa Fe railway by the Baldwin Locomotive Works under the scrutiny of a Santa Fe inspector. It was inspected also by a personal representative of the undersigned, whose daily reports cover progress made and include certificates of analyses and of tests made by him, or in his presence, of the materials entering into the construction of the boiler. These, however, are not important to this presentation, except so far as they concern the details which failed under the low-water tests, and this report need not be cumbered by a full record of such statements. Those facts which are most pertinent will be set forth in connection with the discussion of the results of the low-water tests.

82. Preparations for the low-water tests received careful attention.

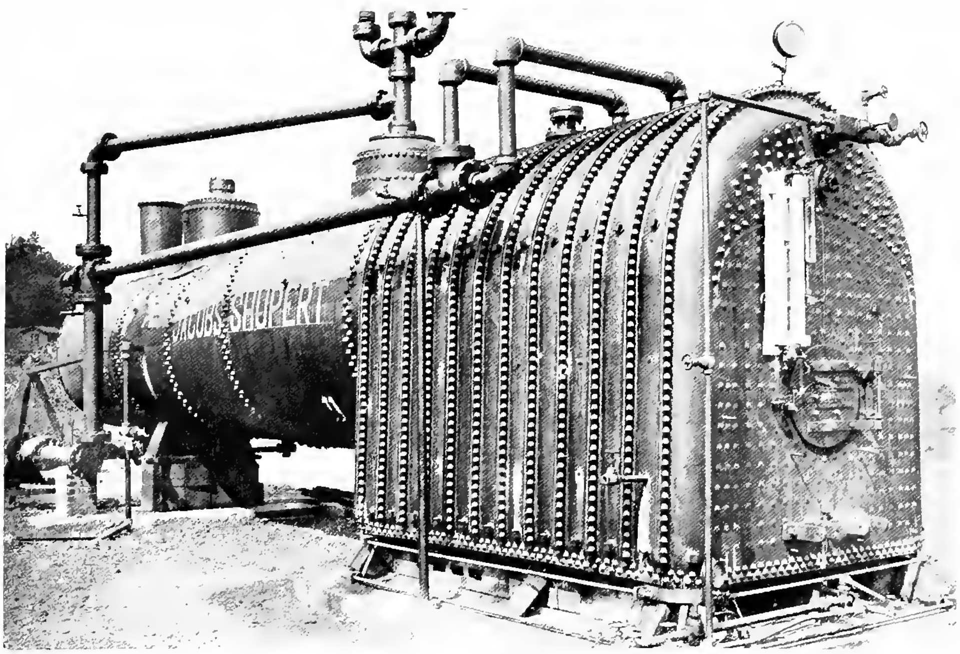


FIG. 71.—View of Jacobs-Shupert boiler in position after low-water test, showing water, oil and steam pipes, valves and connections, the three pops and special water-glasses and gage-boards.

An extensive fill made up of refuse from the mill of the Lukens Iron & Steel Company, extending up the valley of a small stream for a distance of several thousand feet, remote from habitations, supplied an acceptable ground. The fill was traversed by railway tracks over which the mill locomotives and cars were constantly operating. Fig. 65 shows the Jacobs-Shupert boiler on its way to the testing-ground. The upper surface of the fill was fairly level, and at the point chosen for the setting of

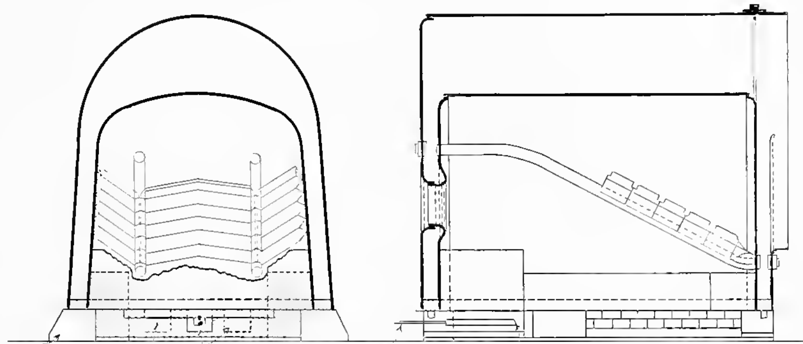


Fig. 72.—General arrangement of oil burner and fixtures and brick arch in test boilers in low-water tests.

the boilers it extended to a width of approximately 200 feet. Each boiler was set on two concrete piers, one under the firebox approximately 10 feet square, and the other under the barrel of the boiler of much smaller dimensions. These are well shown by Figs. 66 and 67. The location of the boilers with reference to each other and to surrounding features of the landscape is shown by Fig. 68, and the general layout of the equipment by Fig. 69. A substantial shelter for those conducting the tests, consisting principally of the firebox-end of a Jacobs-Shupert boiler, was established 200 feet from the nearest boiler (Fig. 70). In the rear of this shelter an oil-tank was erected at such a height as would serve to deliver fuel-oil to the burners under the boilers by gravity, and a small pump near the tank served to take oil from a works tank-car which could be switched to an adjacent track to this service tank. The Jacobs-Shupert boiler with its connected piping, gage-boards, etc., is shown by Fig. 71. The radial-stay boiler was similarly equipped. The boilers were fed with water by means of an independent steam-pumping plant located on the bank of the stream below the fill. A shelter was provided for the attendant of this plant. A main feed line was laid directly from the feed pump to the operators' shelter, at which point it branched to each boiler, a valve in each branch within the shelter permitting a control of the feed during the progress of the tests (Fig. 69). The oil-supply pipe also branched at the shelter, and each branch was provided with valves permitting control at that point. These oil-valves, however, were not used except to shut off

the supply of oil when the boiler being supplied went out of commission. The location of the oil-burner, the design of the brickwork and other details of furnace arrangement are shown by Fig. 72. The draft which during the low-water tests was supplied in the same manner as in the evaporative tests, that is, by discharging steam from the boiler through a normal exhaust pipe and tip, could be controlled from the shelter. This was accomplished by having a ratchet-wheel (Fig. 73) fitted to the stem of the 7-inch valve in the steam-delivery pipe, and two levers carrying dogs to engage the ratchet-wheel. The action of one lever served to open the valve, while that of the other closed it. Either lever could be operated by pulling a wire at the shelter, a counterweight serving to return the lever to its initial position. It had been planned originally to observe the steam pressure and water-level by means of water-glasses and gages located within the shelter, but the possibility of errors appearing in apparatus extended so far from the boilers resulted in a determination to take these readings from apparatus immediately affixed to the boiler. To make this possible two small telescopes were mounted on the top of the operating shelter, by the use of which observers could read with greatest ease the graduations and figures on the steam-gage, and observe accurately the level of the water in the water-glass. One of these glasses is to be seen in Fig. 70, and the instruments to be observed in Figs. 74 and 75.

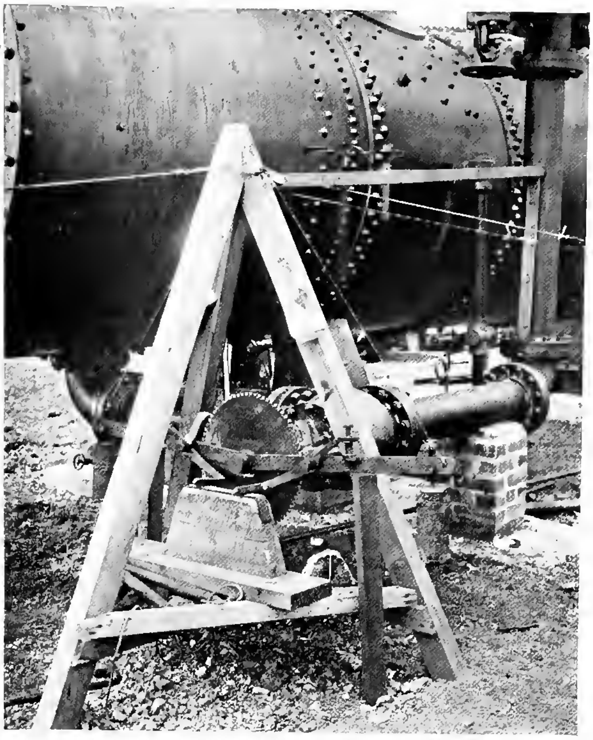


FIG. 73.—Draft regulator for controlling the steam flow through exhaust-pipe of boiler during low-water test. By means of wires the draft could be controlled from the operating shelter.

83. Elaborate provisions were made for the comfort and convenience of official guests. Upon the hillside above and to the rear and at a distance of 600 feet from the nearest boiler, a pavilion (Fig. 76) was erected having seats under roof for 300 guests. A telephone connected the guests' pavilion with the operating shelter, and a large display board was erected to serve in keeping the guests at all times informed as to the steam pressure and the water-level within the boiler under test. Adjacent to the guests' pavilion was a refreshment booth from which lunch could be served to guests arriving by morning trains. A specially con-

structed shelter for the accommodation of a moving-picture machine was located on the hillside at a distance of approximately 300 feet from the boilers. The opposite side of the valley, at distances from the boilers of 1,500 feet or more, supplied an abundance of room for those citizens of the town and vicinity who might desire to witness the tests. Provisions were made for effectively policing the limits of the testing-ground as thus defined.

84. Thursday, the 20th of June, the day set for the tests, was ushered in under a clear sky. The boilers which in anticipation of the day had, after careful internal and external inspection, been declared clean and in perfect order, were early under steam. Guests arriving in the middle of the forenoon were given an opportunity to see all parts of the testing plant, and later by the courtesy of Messrs. A. F. and C. L. Huston, were conveyed on a tour of inspection through the extensive works of the Lukens Iron & Steel Company. To facilitate such inspection, a number of mill cars were fitted with wooden bodies having longitudinal seats for the accommodation of guests. These cars in trains of two or three were moved rapidly from point to point over the entire works and also between the works and the boiler-testing ground. Ladies accompanying guests were especially provided for in the mean time at the home of Mrs. A. F. Huston. Soon after noon the company began to assemble in the visitors' pavilion, and by one o'clock it was filled to overflowing. The townspeople lined the opposite bank of the valley and all the country-side assumed a holiday aspect. The ground about the boilers had been cleared of all but the expert and his immediate assistants. The two boilers which were to be tested were both in action. The roar of their exhaust completely drowned the sounds which otherwise would have filled the valley. Soon after one o'clock a telephone message received at the operating shelter from the

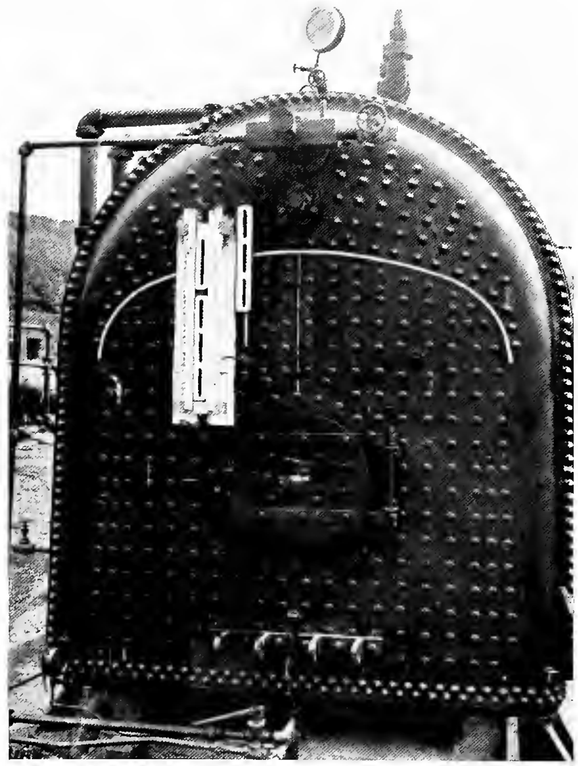


Fig. 74.—Photograph of boiler head of Jacobs-Shupert boiler, showing special water gage-glasses and gage-boards for indicating the water-level in boiler during low-water tests. Readings were made from shelter by means of telescopes.

visitors' pavilion announced the arrival of the last train bearing invited guests. The fire under the radial-stay boiler was immediately suppressed and the steam blast was shut off. The Jacobs-Shupert boiler, the first to be tested, was brought under conditions which had been carefully predetermined. The valve controlling the discharge of steam from the exhaust tip was carefully adjusted until the draft-gage connecting with the front-end indicated 6 inches of water. The oil supplied the fire was next adjusted to give as heavy a fire as could be sustained by this draft without black smoke. Preliminary tests had shown that this condition of draft and fire with the boiler in question could be relied upon to evaporate approximately 30,000 pounds of water per hour, or 10 pounds of water per foot of heating-surface per hour. This condition is not the maximum to which the boiler could be forced, but was accepted as representing that which under road conditions would be regarded as a heavy normal load. Upon the report from the attendants that the predetermined conditions had been secured, a committee of three engineers consisting of Mr. Charles Ducas, Mr. J. F. Butler, and Mr. P. C. Haldeman were requested to inspect carefully the boiler as it was then operating and to report to the undersigned whether all conditions were in accordance with the program. After eight or ten minutes this committee returned to the shelter, reporting that all conditions, including the draft, the fire, the water-level, the steam pressure, etc., were as stated, whereupon it was announced from the shelter that the tests would begin.

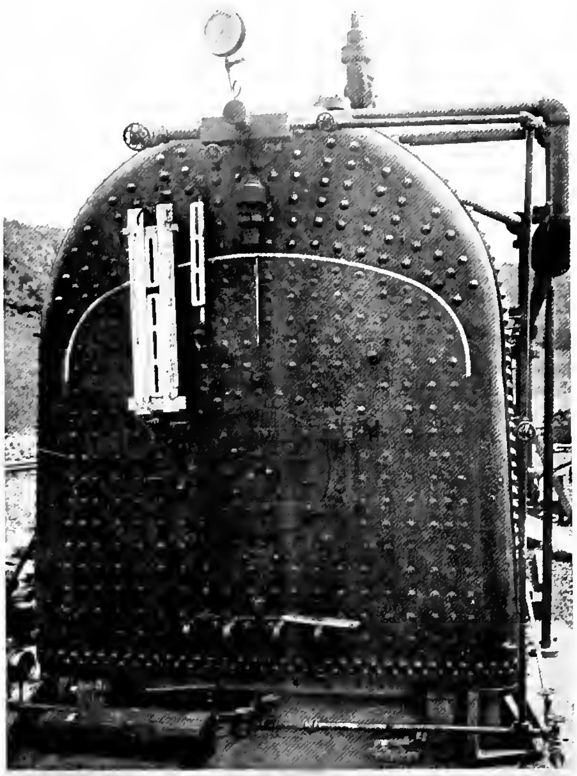


Fig. 75.—Photograph of boiler head of radial-stay boiler showing special water gage-glasses and gage-boards for indicating the water-level in boiler during low-water test. Readings were made from shelter by means of telescopes.

85. The organization at the shelter was as follows:

Charles Ducas. Time-keeper. It was Mr. Ducas' part to call out a warning and to give a signal at 30-second intervals. Mr. Ducas also made the necessary changes in the display boards, which served to indicate

to the guests the condition of steam pressure and water-level after each observation.

J. F. Butler. Observer of water-levels and checker of steam-gage readings at Telescope A.

P. C. Haldeman. Observer of gage readings and checker of water-levels at Telescope B.

A. M. Baird. Assistant in immediate charge of boiler operation.

H. S. Coleman. Log keeper.

W. Seachrist. Valve operator within the shelter.

W. F. M. Goss. Expert in charge.

86. The test of the Jacobs-Shupert boiler began at 1.48 P.M. Upon signal from the time-keeper, observations were reported and noted upon the log in the following order:

(*a*) Water-level
(*b*) Steam pressure
(*c*) Number of pops blowing.

After these entries were complete, the check readings were announced. By observing this order of procedure there was never confusion, though the time interval between observations was short. The expert in charge had before him a plotted diagram with the 30-second intervals marked off as abscissæ, and upon which he noted the water-levels as ordinates so that the history of the tests at any particular moment was completely under his eye. All changes in the setting of valves was in response to verbal direction from the expert in charge. The procedure thus described was persisted in without interruption until the test was terminated. The water left the crown-sheet at 1.49⅙ P.M., and its level steadily declined for 34⅙ minutes when it had fallen to the bottom of the special water-glass 25½ inches below the crown-sheet. The steaming capacity of the boiler declined as the water-level fell. In the beginning, besides the steam passing out of the exhaust pipe, a large volume was discharged by the safety-valves, but with the fall of water-level the amounts thus discharged diminished until the valves ceased to open. The pressure then declined, the blast became less effective, the draft weakened, and the fire became smoky. Twice the throttle opening was increased to stimulate the draft, but the pressure ran down the more rapidly. Fifty-five minutes after the beginning of the test upon the Jacobs-Shupert boiler, the water-level had fallen to a point where the barrel of the boiler was less than one-fourth filled, and the capacity of the boiler to generate steam had so diminished that the draft conditions with which the test started could no longer be maintained. The oil supply had not been changed and an enormous cloud of black smoke issued from the stack. When the steam pressure had fallen to 50 pounds, the low-water test of the Jacobs-Shupert boiler was ended. It had been boiled nearly dry and no failure had occurred.

87. Immediately upon the termination of the test of the Jacobs-Shupert boiler, fire was restarted under the radial-stay boiler. Approximately half an hour was required in which to bring this boiler to a condi-

tion of operation identical with that which defined the operation of the Jacobs-Shupert boiler. The conditions when secured were announced, the test was started, and the record kept in precisely the same way as had been previously done. When the water had fallen in the water-glass to a point which was 14½ inches below the crown-sheet, 17¾ minutes after the water had fallen to the level of the crown-sheet, the spectators heard above the steady roar of the exhaust a loud report and saw a great cloud

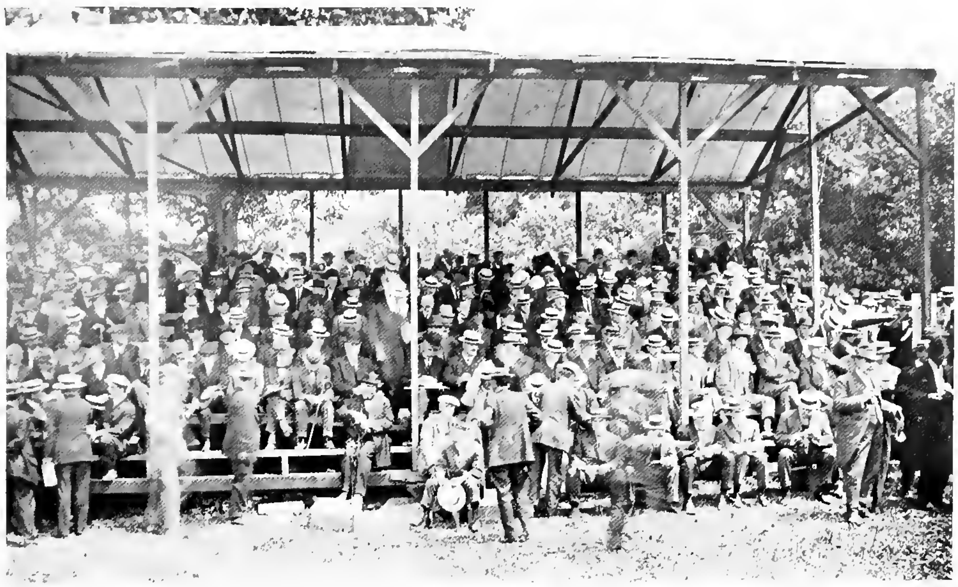


FIG. 76.—The guests' pavilion erected on the hillside about 600 feet from nearest boiler and some of the 500 guests. Telephone communication with operating shelter and the display board served to keep the guests informed at all times of conditions in the boilers.

of steam, rolling out in all directions from the neighborhood of the mud-ring, quickly envelop the entire boiler and its immediate surroundings. Every one understood that the test of the radial-stay boiler under low-water conditions was over and that the boiler had failed.

88. Among those who witnessed the tests as invited guests were many distinguished practising and consulting engineers, railway officials, college professors and scientists, a committee formally appointed by the Master Boiler Makers' Association, and others having interest in the event. Those from the City of Coatesville and vicinity, who occupied positions of advantage along the opposite side of the valley, were estimated by the newspapers of the city as from eight to ten thousand.

89. The arrangements incidental to the reception of special guests, the policing of the grounds, and the handling of the crowd were all under the immediate direction of the officers of the Jacobs-Shupert United States Firebox Company and of the Lukens Iron & Steel Company.

90. A detailed study of the tests supplies a more accurate definition of what occurred. A copy of the log of the test of the Jacobs-Shupert boiler is presented herewith as Table 4, and a copy of the log of the test of the radial-stay boiler as Table 5. Prior to the beginning of the tests, a tentative curve showing a proposed rate at which the water-level should be allowed to decline was drawn, and an attempt to parallel this curve in the actual test led to the feeding of both boilers for brief intervals in the early part of the test. It soon became apparent, however, that the actual curve would run above the assumed curve, and consequently no feeding was employed except in the early part of the test. In the Jacobs-Shupert boiler the feed was on for a total of 2½ minutes during the first 5 minutes of the test, after which the whole process was simply one of boiling away the water contained by the boiler. In the radial-stay boiler the feed was on 2 minutes during the first 7 minutes of the test only. The fall of the water-level in both boilers is shown graphically by Fig. 77. In the execution of the tests, the main purpose was to secure a rate of fall in the water-level which should be substantially the same for both boilers. The degree of success in meeting these requirements is well shown by Fig. 77. This figure also shows the steam pressure for both boilers throughout the tests. It will be seen that both boilers lost water at substantially the same rate for the first 22½ minutes of the test. At the end of this time, the radial-stay boiler had failed, but the Jacobs-Shupert boiler continued in operation without diminution in the amount of oil burned for 30½ minutes longer. The radial-stay boiler failed in less than 18 minutes after the water was observed at the crown-sheet level. The Jacobs-Shupert boiler was operated 53 minutes after the water was observed at the crown-sheet level.

91. The water-levels entered upon the logs Tables 4 and 5 are those actually observed from the water-glass attached to the back-head of the boiler. The water column in the water-glass, however, was presumably heavier than the mixture of water and steam within the boiler, and consequently the surface of the water inside of the boiler must have been somewhat higher than the level observed upon the glass outside. The difference between the observed and the actual water-level within the boiler is not easily estimated, and no attempt has been made to establish the actual water level within the boiler, except as it was made apparent at the close of the test by the color effects upon the heating-surface. It should be clear, however, that the surface of the water within the boiler did not fall below the level of the crown-sheet at the instant which the observations indicate, and that the actual decline in the boiler for all portions of the test lagged a little behind the record of the observed results.

92. Many of those who witnessed the tests received the impression that the Jacobs-Shupert boiler did not steam as freely as the radial-stay boiler. Two causes operated to give rise to such an impression: First, it is true that during the first 6 minutes of the test of the Jacobs-Shupert

LOW WATER TESTS—SERIES C

Log of Boiler Conditions During Test

Table 4

JACOBS-SHUPERT BOILER

TIME (30 SECOND INTERVALS)	MINUTES FROM TIME WATER WAS AT CROWN SHEET	LEVEL OF WATER ABOVE OR BELOW CROWN SHEET	STEAM PRESSURE GAUGE, LBS.	NUMBER OF POPS BLOWING	BOILER FEED WATER
1.48 P.M.	....	½" Above	225	3	On
1.48½	....	½" "	220	2	Off
1.49	....	¼" "	220	2	On
1.49½	½	½" Below	220	2	Off
1.50	....	½" "	220	2	"
1.50½	1½	¾" "	220	2	"
1.51	...	1¼" "	220	2	On
1.51½	2½	1¼" "	220	2	"
1.52	....	1¼" "	220	2	"
1.52½	3½	1½" "	220	2	Off
1.53	....	1¾" "	215	1	"
1.53½	4½	1¾" "	215	1	"
1.54	....	2 " "	220	2	"
1.54½	5½	2½" "	223	3	"
1.55	....	2¾" "	223	3	"
1.55½	6½	3 " "	223	3	"
1.56	....	3½" "	223	3	"
1.56½	7½	4 " "	223	3	"
1.57	....	4½" "	223	3	"
1.57½	8½	4½" "	222	3	"
1.58	....	5¼" "	222	3	"
1.58½	9½	5½" "	222	3	"
1.59	....	6 " "	222	3	"
1.59½	10½	6 " "	222	3	"
2.00	....	6¼" "	222	3	"
2.00½	11½	6½" "	222	3	"
2.01	...	6½" "	220	2	"
2.01½	12½	6¾" "	220	2	"
2.02	...	6¾" "	220	2	"
2.02½	13½	6¾" "	220	2	"
2.03	....	6¾" "	220	2	"
2.03½	14½	7 " "	220	2	"
2.04	....	7½" "	220	2	"
2.04½	15½	7¾" "	220	2	"
2.05	....	8¼" "	220	2	"
2.05½	16½	8¾" "	218	2	"
2.06	....	9 " "	218	2	"
2.06½	17½	9½" "	220	2	"
2.07	....	12 " "	220	2	"
2.07½	18½	12½" "	220	2	"
2.08	....	13 " "	215	1	"
2.08½	19½	13½" "	220	2	"
2.09	....	13½" "	220	2	"
2.09½	20½	13½" "	220	2	"
2.10	....	13½" "	215	1	"
2.10½	21½	14 " "	218	2	"
2.11	....	15 " "	220	2	"
2.11½	22½	15¾" "	218	2	"
2.12	....	16 " "	218	2	"
2.12½	23½	16½" "	220	2	"
2.13	...	17 " "	215	1	"
2.13½	24½	17½" "	220	2	"
2.14	....	17¾" "	215	1	"
2.14½	25½	18¼" "	215	1	"

LOW WATER TESTS—SERIES C (Continued)

Table 4

TIME (30 SECOND INTERVALS)	MINUTES FROM TIME WATER WAS AT CROWN SHEET	LEVEL OF WATER ABOVE OR BELOW CROWN SHEET	STEAM PRESSURE GAUGE, LBS.	NUMBER OF POPS BLOWING	BOILER FEED WATER
2.15	....	19 " Below	210	1	Off
2.15½	26⅙	19¼" "	208	0	"
2.16	....	20 " "	210	0	"
2.16½	27⅙	20 " "	208	0	"
2.17	....	20½" "	205	0	"
2.17½	28⅙	20½" "	200	0	"
2.18	....	21½" "	200	0	"
2.18½	29⅙	21¾" "	200	0	"
2.19	....	22 " "	200	0	"
2.19½	30⅙	22½" "	200	0	"
2.20	....	23 " "	197	0	"
2.20½	31⅙	23¼" "	195	0	"
2.21	....	23¾" "	195	0	"
2.21½	32⅙	24 " "	190	0	"
2.22	....	24¼" "	190	0	"
2.22½	33⅙	24½" "	187	0	"
2.23	....	25 " "	187	0	"
2.23½	34⅙	25½" "	185	0	"
2.24	....	....	185	0	"
2.24½	35⅙	....	185	0	"
2.25	....	....	180	0	"
2.25½	36⅙	....	178	0	"
2.26	....	....	175	0	"
2.26½	37⅙	....	170	0	"
2.27	....	....	167	0	"
2.27½	38⅙	....	163	0	"
2.28	....	....	155	0	"
2.28½	39⅙	....	150	0	"
2.29	....	....	145	0	"
2.29½	40⅙	....	143	0	"
2.30	....	....	140	0	"
2.30½	41⅙	....	130	0	"
2.31	....	....	125	9	"
2.31½	42⅙	....	120	0	"
2.32	....	....	118	0	"
2.32½	43⅙	....	105	0	"
2.33	....	....	103	0	"
2.33½	44⅙	....	100	0	"
2.34	....	....	...	.	"
2.34½	45⅙	....	95	0	"
2.35	....	....	90	0	"
2.35½	46⅙	....	89	0	"
2.36	....	....	90	0	"
2.36½	47⅙	....	88	0	"
2.37	....	....	80	0	"
2.37½	48⅙	....	77	0	"
2.38	....	....	75	0	"
2.38½	49⅙	....	73	0	"
2.39	....	....	70	0	"
2.39½	50⅙	....	70	0	"
2.40	....	....	65	0	"
2.40½	51⅙	....	60	0	"
2.41	....	....	57	0	"
2.41½	52⅙	....	55	0	"
2.42	....	....	53	0	"
2.42½	53⅙	35" (Est.)	50	0	"
Test Stopped					

LOW WATER TESTS—SERIES C

Log of Boiler Conditions During Test

Table 5

RADIAL-STAY BOILER

TIME (30 SECOND INTERVALS)	MINUTES FROM TIME WATER WAS AT CROWN SHEET	LEVEL OF WATER ABOVE OR BELOW CROWN SHEET	STEAM PRESSURE GAUGE, LBS.	NUMBER OF POPS BLOWING	BOILER FEED WATER
3.35 P.M.	....	2½" Above	230	3	On
3.35½	....	2½" "	233	3	"
3.36	....	2½" "	230	3	Off
3.36½	....	2½" "	223	3	"
3.37	....	2¼" "	220	2	"
3.37½	....	1¾" "	223	2	"
3.38	....	1½" "	225	3	"
3.38½	....	1¼" "	228	3	"
3.39	....	¾" "	230	3	"
3.39½	....	¼" "	230	3	"
3.40	¼	¼" Below	230	3	"
3.40½	....	1 " "	230	3	On
3.41	1¼	1¼" "	233	3	Off
3.41½	....	1½" "	230	3	On
3.42	2¼	1¾" "	230	3	Off
3.42½	....	2 " "	230	3	"
3.43	3¼	2¼" "	228	3	"
3.43½	....	2½" "	230	3	"
3.44	4¼	3 " "	230	3	"
3.44½	....	3¼" "	230	3	"
3.45	5¼	3¾" "	230	3	"
3.45½	....	4¼" "	230	3	"
3.46	6¼	4½" "	230	3	"
3.46½	....	5 " "	230	3	"
3.47	7¼	5½" "	233	3	"
3.47½	....	6 " "	233	3	"
3.48	8¼	6½" "	233	3	"
3.48½	....	7 " "	230	3	"
3.49	9¼	7½" "	233	3	"
3.49½	....	7½" "	233	3	"
3.50	10¼	8 " "	233	3	"
3.50½	....	8¼" "	233	3	"
3.51	11¼	8½" "	233	3	"
3.51½	....	8¾" "	233	3	"
3.52	12¼	9 " "	233	3	"
3.52½	....	9½" "	233	3	"
3.53	13¼	10 " "	233	3	"
3.53½	....	10¼" "	233	3	"
3.54	14¼	11 " "	233	3	"
3.54½	....	11½" "	233	3	"
3.55	15¼	12½" "	233	3	"
3.55½	....	12¾" "	233	3	"
3.56	16¼	13 " "	233	3	"
3.56½	....	13½" "	233	3	"
3.57	17¼	14¼" "	233	3	"
3.57½	....	14½" "	228	3	"
3.57¾	18	Boiler Failed			

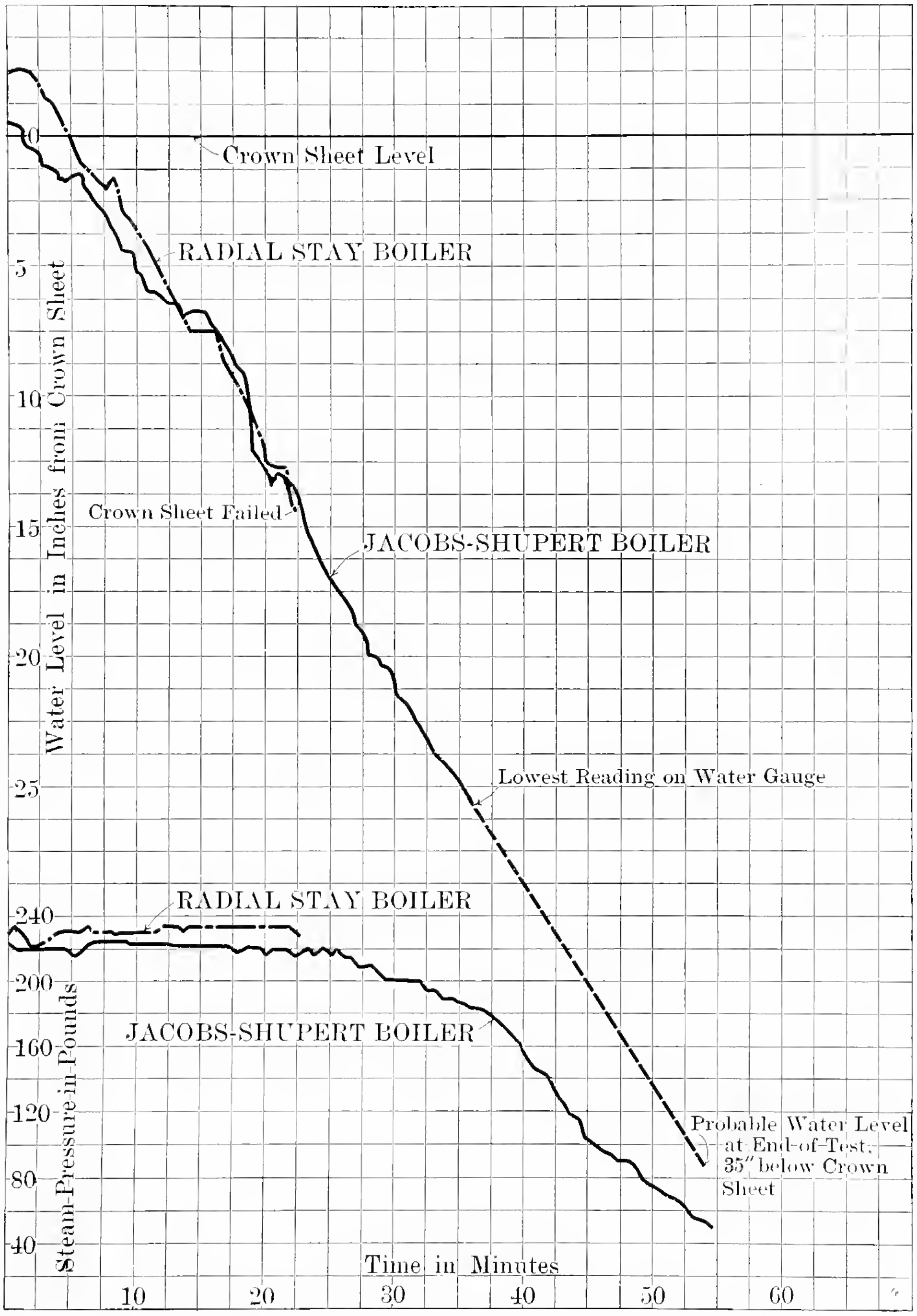


FIG. 77.—Water-levels and steam pressures in boilers during low-water tests.

boiler, the excess of steam generated over that required to produce the draft was successfully discharged by two safety-valves, whereas throughout the corresponding period the three safety-valves of the radial-stay boiler were always open. An explanation of this action is to be found in the fact that the Jacobs-Shupert boiler was not so well supplied with water at the start, and as shown by the record was fed liberally during the first

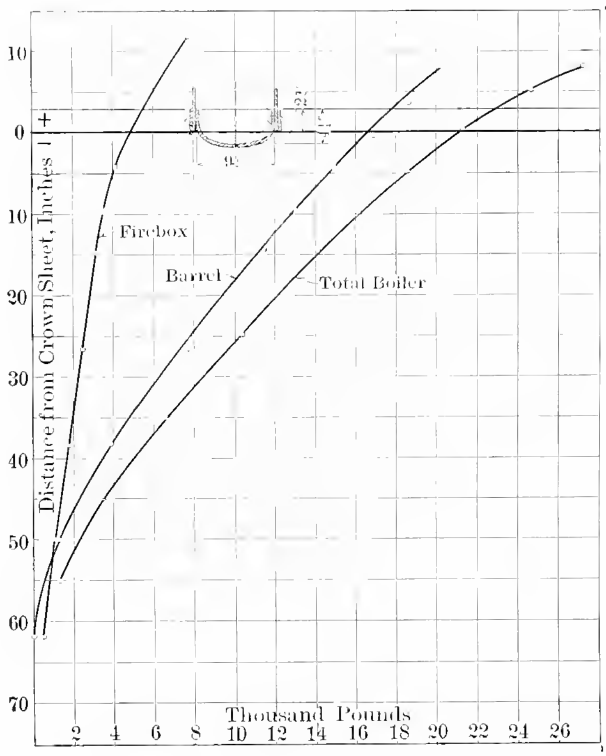


FIG. 78.—Calibration of Jacobs-Shupert boiler, showing water capacity at various levels.

few minutes of the test. Second, another condition which influenced the spectator grew out of the fact that the test of the Jacobs-Shupert boiler endured for 32½ minutes longer than that of the radial-stay boiler. The spectator was naturally more impressed by the conditions prevailing during the last half hour of the test than by those prevailing during the earlier portions thereof. He knew that the water-level was steadily receding, failure seemed imminent, and he was in the attitude of expectancy. His condition of mind and the fact that during this interval the quantity of steam discharged steadily declined, accounts for the impression referred to. Such an impression so far as it has reference to that portion of the test of the Jacobs-Shupert boiler which is comparable with the entire period of endurance of the radial-stay boiler finds no justification in the records of the tests.

93. The fact that after nearly a half hour of operation without feed, the delivery of steam from the Jacobs-Shupert boiler diminished as the test proceeded is to be accounted for in several ways: First, as the heating-

surface of the boiler became bared, its evaporative capacity necessarily diminished; second, with heating-surface bare, the steam delivered became superheated and the safety-valves were called upon to handle a reduced weight of steam, each pound of which carried away an increasing amount of heat; third, as the heating-surface became bare, the heat of the furnace was in part absorbed in raising the temperature of the metal of the boiler, not only the firebox and the tubes, but indirectly through the increased temperature of the steam within the boiler, the shell, and all parts to which the steam had access. Heat could not be taken from the firebox to raise the temperature of the steam and to increase the temperature of metallic parts of the boiler and at the same time evaporate as much water as was possible before these new avenues of heat absorption appeared. The working out of this process and the fact that the test of the Jacobs-Shupert boiler proceeded until 78 per cent. of the water it contained had been evaporated, explains the significance of the observed action.

94. As already stated, it was the purpose in the case of each boiler to start under conditions which would insure the evaporation of approxi-

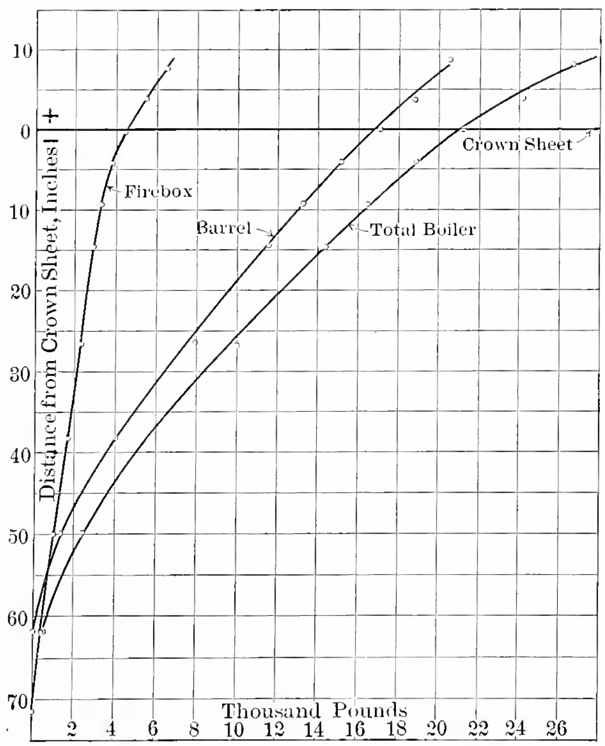


FIG. 79.—Calibration of radial-stay boiler, showing water capacity at various levels.

mately 10 pounds of water per foot of heating-surface per hour. This is equivalent to a total of 30,000 pounds per hour. It has just been shown that at whatever rate the boilers may have been started, the output in the form of water evaporated must have steadily declined as the test proceeded. It would be interesting to know what was the rate of this

decline. Data for such an inquiry are supplied by the known weight of water contained by the boiler for every surface-level and the observed rate at which the surface-level receded. An attempt to make use of these data leads to inconsistencies resulting, no doubt, from unavoidable errors in observation caused by the surging of the water in the gage-glass. But however inaccurate, the results of such an investigation are not without interest, and brief reference may therefore be made to them.

95. The calibrated water capacity of the Jacobs-Shupert boiler is given by the lower curve of Fig. 78, and that of the radial-stay boiler by the lower curve of Fig. 79. The curves are practically the same for both boilers. The rate of fall in water-level during the low-water test is recorded in the logs of the tests Tables 4 and 5. From facts thus available, computations have been made as follows-:

96. Concerning Rate of Evaporation, Jacobs-Shupert Boiler:

FIVE-MINUTE INTERVALS	POUNDS OF WATER EQUIVALENT TO DROP IN WATER LEVEL FOR FIVE-MINUTE INTERVALS	POUNDS OF WATER PER HOUR	MINUTES DURING WHICH FEED VALVE TO BOILER WAS OPEN
1:48 to 1:53	1,300	15,600	2.5
1:53 to 1:58	2,000	24,000	0.0
1:58 to 2:03	875	10,500	0.0
2:03 to 2:08	2,825	33,900	0.0
2:08 to 2:13	1,700	20,400	0.0
2:13 to 2:18	1,875	22,500	0.0
2:18 to 2:23	1,325	15,900	0.0

The boiler feed-valve was open during one-half of the first interval embraced by those computations. The weight of water fed, if it were known, should be added to the value given in the second column. It is known that the rate of feed more than equaled the rate of evaporation so that the actual rate of evaporation during this interval must have been more than double 15,600 pounds. At 2:23.5 the water passed below the bottom of the gage-glass which was 25.5 inches below the crown-sheet. The calibration curve (Fig. 78) shows that there was then a little more than 10,000 pounds of water in the boiler, which when filled to the middle gage-cock, contains 30,000 pounds.

97. Concerning Rate of Evaporation, Radial-stay Boiler:

FIVE-MINUTE INTERVALS	POUNDS OF WATER EQUIVALENT TO DROP IN WATER LEVEL FOR FIVE-MINUTE INTERVALS	POUNDS OF WATER PER HOUR	MINUTES DURING WHICH FEED VALVE TO BOILER WAS OPEN
3:35 to 3:40	1,600	19,200	1.0
3:40 to 3:45	1,800	21,600	1.0
3:45 to 3:50	1,800	21,600	0.0
3:50 to 3:55	2,200	26,400	0.0

Fig. 80.—Photograph of Jacobs-Shupert firebox after low-water test, showing brick arch in place and in perfect condition. The light spot on flue-sheet at center of crown-sheet is the visible record of the only leak observed in the firebox after the test.

Fig. 81.—The center portion of the Jacobs-Shupert firebox after the low-water test. The sections shown in the photograph received the most severe overheating and were badly scaled and discolored. The line of demarcation is seen clearly on the right side-sheet.

It will be seen that the values deduced for the first two intervals are affected by the introduction of feed-water. The weight of water fed should, of course, be added to the value in the second column. At 3:57¾ the boiler failed. It contained at the time of failure something more than 14,000 pounds of water.

98. The conclusion of the low-water test as applied to the Jacobs-Shupert boiler found that boiler undisturbed and apparently ready for service. After having boiled nearly dry, when its steam pressure had fallen to 50 pounds, the test was terminated by shutting off the blast and

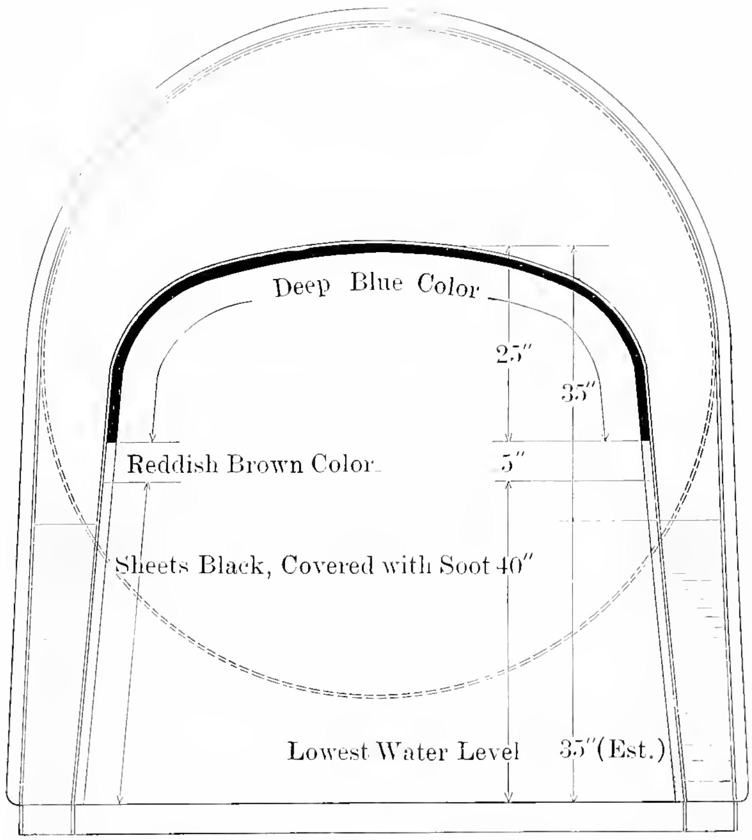


Fig. 82.—Discoloration of firebox sheets from overheating—Jacobs-Shupert boiler. Section through firebox section No. 5.

the fuel supply. An hour later, after the test of the radial-stay boiler had been completed, an inspection, through the door of the Jacobs-Shupert boiler, disclosed portions of the brick arch still sufficiently heated to glow. A description of a detailed inspection of this boiler which was made later is as follows:

99. The Jacobs-Shupert firebox, as photographed through the door after the test, is shown by Figs. 80 and 81. In both of these views the brick arch is seen to be wholly undisturbed and in perfect condition. Later, this arch was removed and the boiler was turned on its side to facilitate inspection. When in this position, the photographs shown by

Figs. 83 and 84 were taken. A well-defined line of demarcation was found to run around the firebox approximately 34 inches below the stay-sheet calking line in the crown of the firebox. The line presented waves as it passed the convolutions of the several sections, its maximum and minimum limits being those shown by Fig. 84. Portions of the sections below this line were soot covered and normal in appearance. Higher up and in more exposed portions of the firebox the sections had the color and appearance of freshly heated steel. The more highly heated portions were flecked

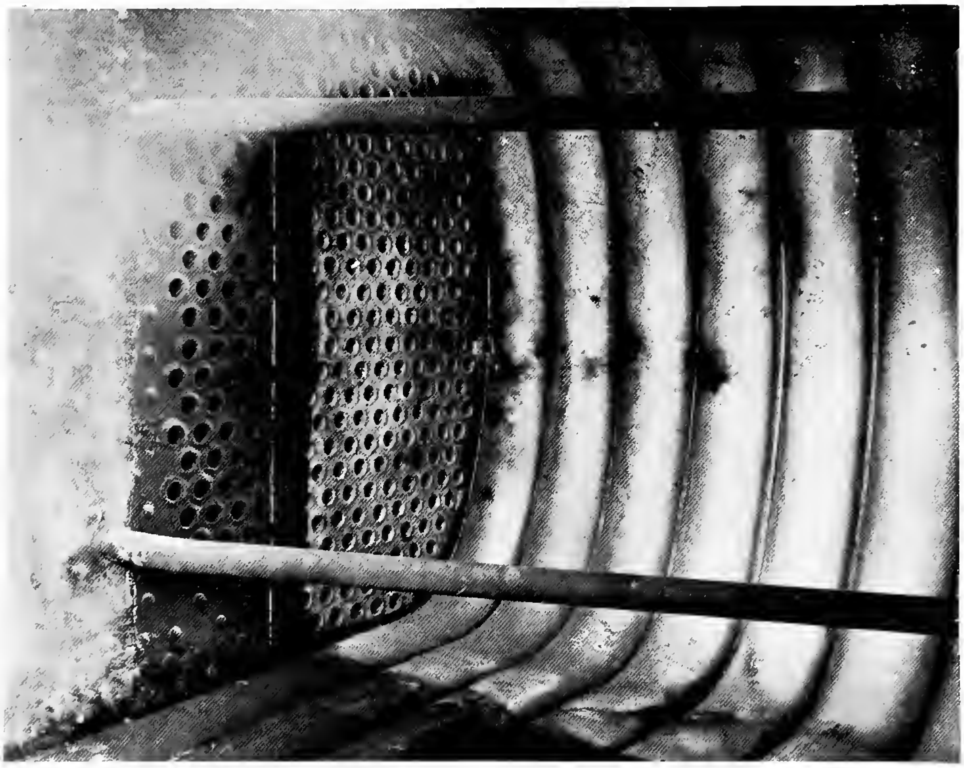


Fig. 83.—View of forward portion of Jacobs-Shupert firebox after low-water test, showing first five sections and flue-sheet. Above the line of demarcation the steel is of dark blue color, and the surface scaled from intense overheating. The blue shades off into reddish brown, and lower down into sooty black.

with scales, resulting from oxidation (Fig. 81). Between the portions which were soot covered and those which bore the appearance of freshly heated steel was a belt approximately 5 inches in width which was generally reddish brown in color shading off into the black which was below and into the freshly heated steel above (Fig. 82).

100. The firebox was made up of eleven sections. A critical examination of these, taking them in order beginning with the forward section, resulted as follows: The first section was found to show the color of newly heated steel on the curved portion, the effect being most striking on the lower side (Fig. 83). This color did not anywhere extend entirely around to the stay-sheet. A few scales of oxidation only were found on this

section. The five successive sections, all of which appear in Fig. 83, were found to be similar except that each succeeding section bore evidence of increased heating effects. The hottest sections in the whole boiler were five and six, and these sections, as well as section seven, gave evidence of having been highly heated on the sides as well as in the crown. Sections five and six were thickly covered with scale (Fig. 81). Section eight was found to have only a portion of its area the color of newly heated steel, and sections nine, ten, and eleven were found to be, within the heated zone, entirely of the reddish brown color (Fig. 84).

101. Those most affected disclosed a curvature which drops one-half inch more than that which was originally given them. The change in contour, while not entirely regular, disclosed no evidence of a disposition to develop pockets or to local failure by blowing out. The final contours of the section were accurately outlined by means of templets made from

FIG. 84.—Rear portion of the Jacobs-Shupert firebox after low-water test. Discoloration of last four sections and door-sheet from overheating is clearly shown.

the sheets. Facsimiles of these templets are shown for all eleven sections in Figs. 85 to 95 inclusive. In these figures the side contours were taken 24 inches on either side of the center line of the firebox. It is noteworthy that, notwithstanding the high temperature to which this firebox was subjected, the color of newly heated metal nowhere extends around the section to a stay-sheet, nor was there any point on the calking edge of the stay-sheet which had been heated beyond that temperature which

results in the reddish brown color. Nothing in the appearance of the sections or of the stay-sheets indicated the presence of the least leak through the crown.

101*a*. The back tube-sheet as shown in Fig. 83 was found to disclose a clearly defined water-line, which is 31¼ inches below the crown. The color of the greater portion of the area of this sheet is that of freshly heated metal. For two or three inches above the clearly defined water-line and for six or more inches around the edges of the sheet it was reddish brown. The tube-sheet was found to retain very nearly its original shape. On either side of the center and near the middle of the heated zone, where in the design of the boiler there is a considerable area unsupported by tubes, the plate was bulged to the extent of one-fourth inch. At the crown of the tube-sheet, as shown by Figs. 80 and 83, a small leak had developed. The joint at this point is made by riveting the first section of the firebox to the tube-sheet with a copper calking strip between. It is at the crown of this joint that the evidence of the leak appears. This leak, the only one to be found in the firebox, was slight. It could not have interfered with the normal operation of the boiler.

101*b*. Within the highly heated area of the tube-sheet, shown in Fig. 83, are 188 tubes. Naturally the upper tubes were most affected by the heat to which they were exposed. Four of the tubes were found to have collapsed just inside of the tube-sheet, 14 others, making 18 altogether, were found pulled apart inside of the sheet. The weld between the tube and the sheet was not disturbed in any case. It is probable that, except in the case of those which collapsed, the actual rupture of these various tubes occurred in the process of cooling after the test had been finished. All other tubes were intact so far as their contact with the back tube-sheet is concerned. All those within the heated zone were found deflected downward, the deflection varying from a comparatively small amount to an amount equal to the diameter of the tubes. The tubes which at the conclusion of the test were below the water-line remained in their original straight condition.

102. The door-sheet of the firebox (Fig. 84) was not greatly affected by the conditions imposed by the test. No distinctly marked water-line appears upon this sheet, though the upper portion had the mottled reddish brown and black appearance. There was no distortion of this sheet and no evidence of leaking stay-bolts.

103. The arch tubes (Figs. 80 and 81) were not disturbed or affected by the test, and the arch at the conclusion of the test was, as already noted, in perfect condition. The mottled appearance of the arch tubes in some of the photographs results from a disturbance of the soot which covered them.

104. A review of these conditions discloses the fact that so far as the firebox construction is concerned, the boiler at the conclusion of the test was in condition for operation.

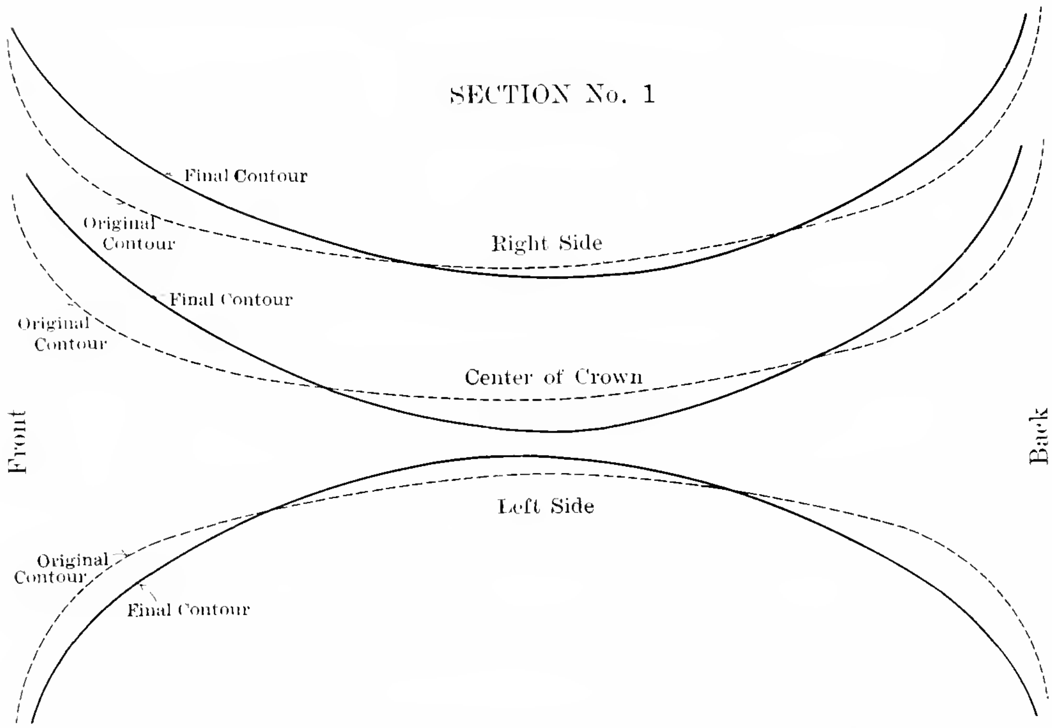


Fig. 85.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

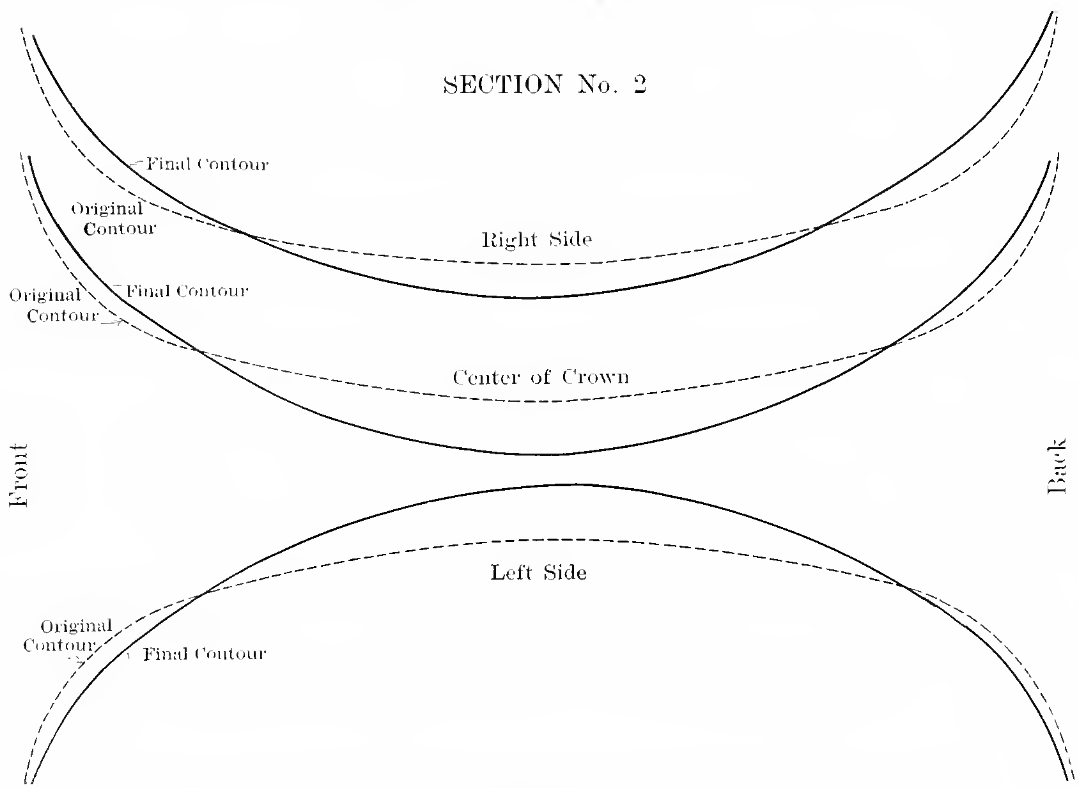


Fig. 86.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

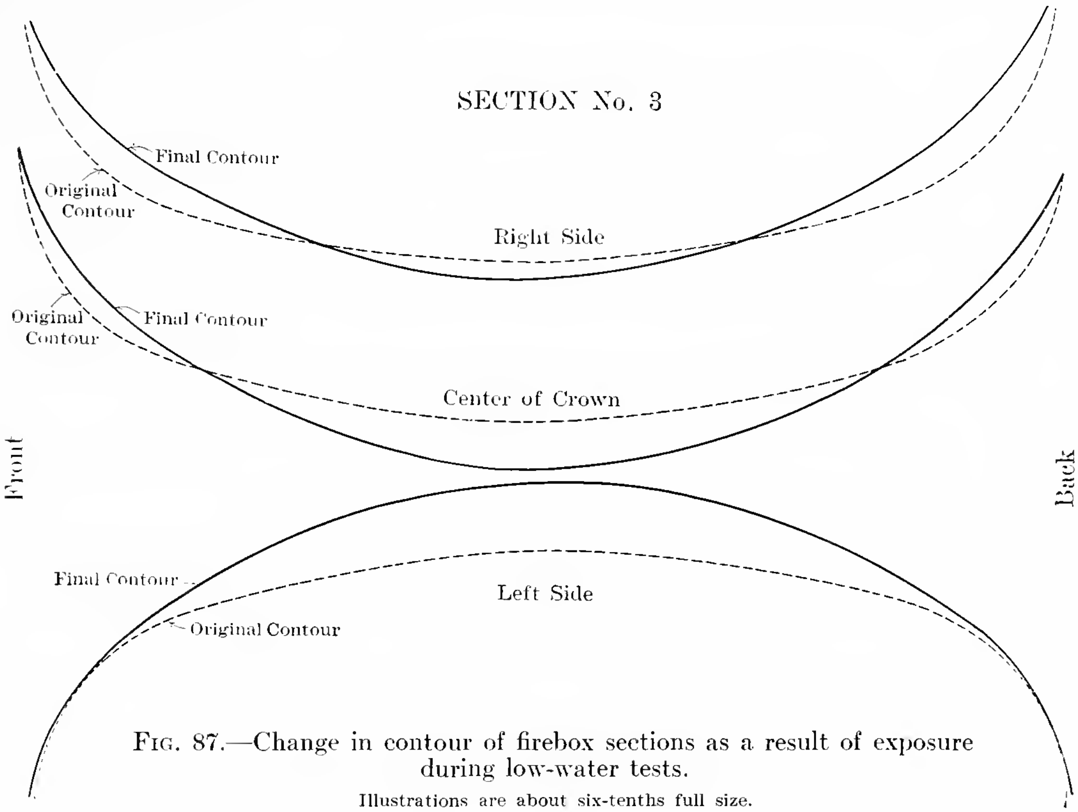


FIG. 87.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

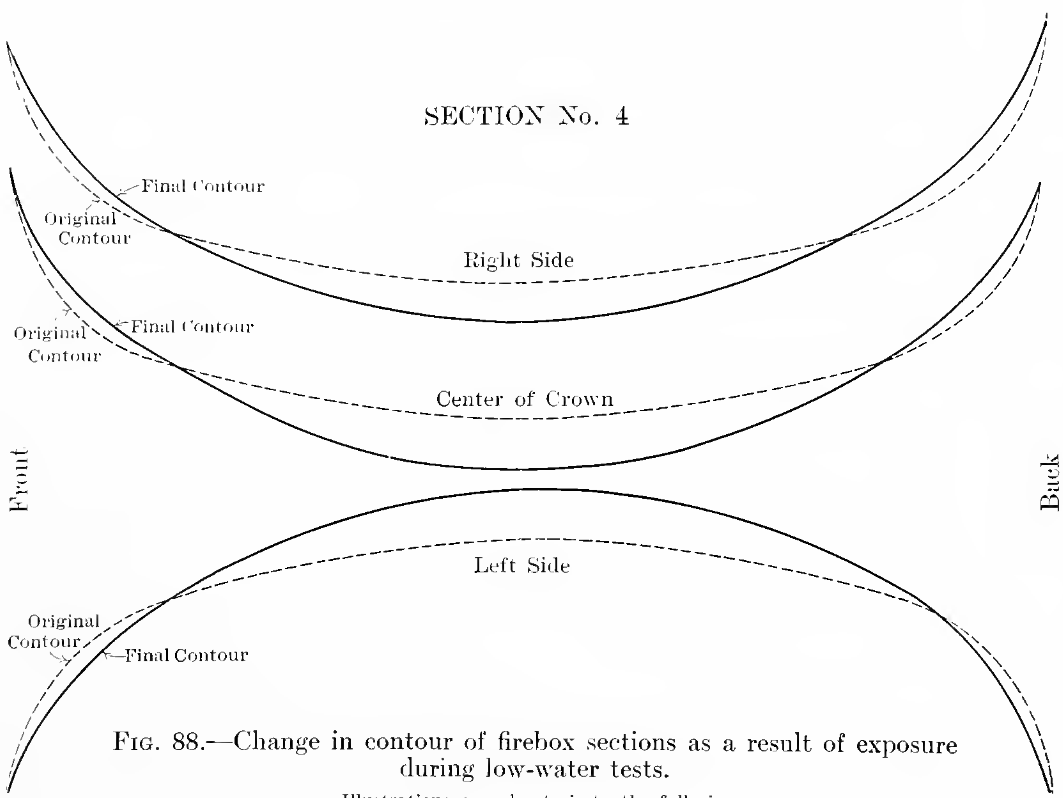


FIG. 88.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

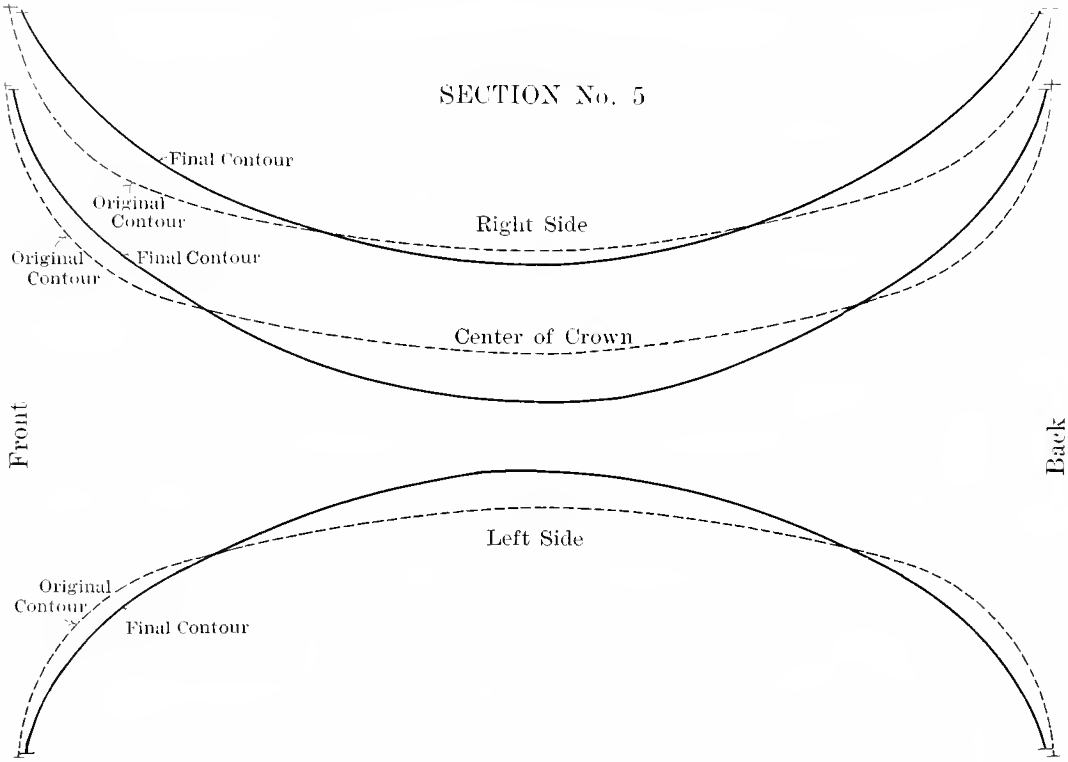


FIG. 89.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

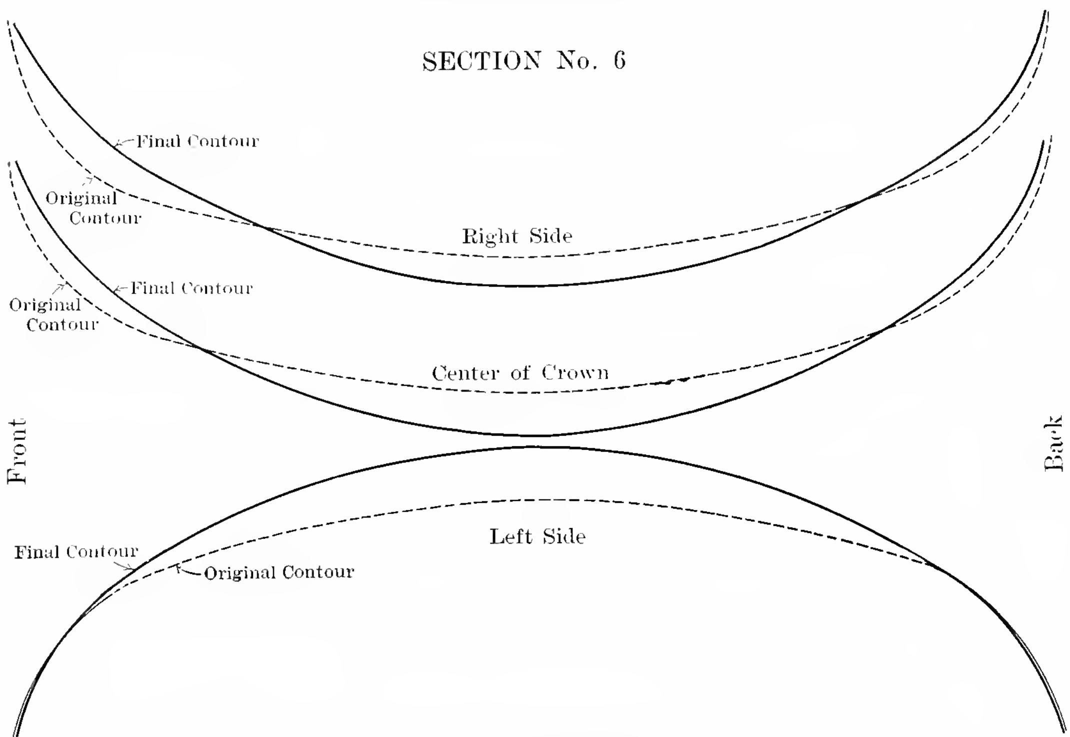


FIG. 90.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

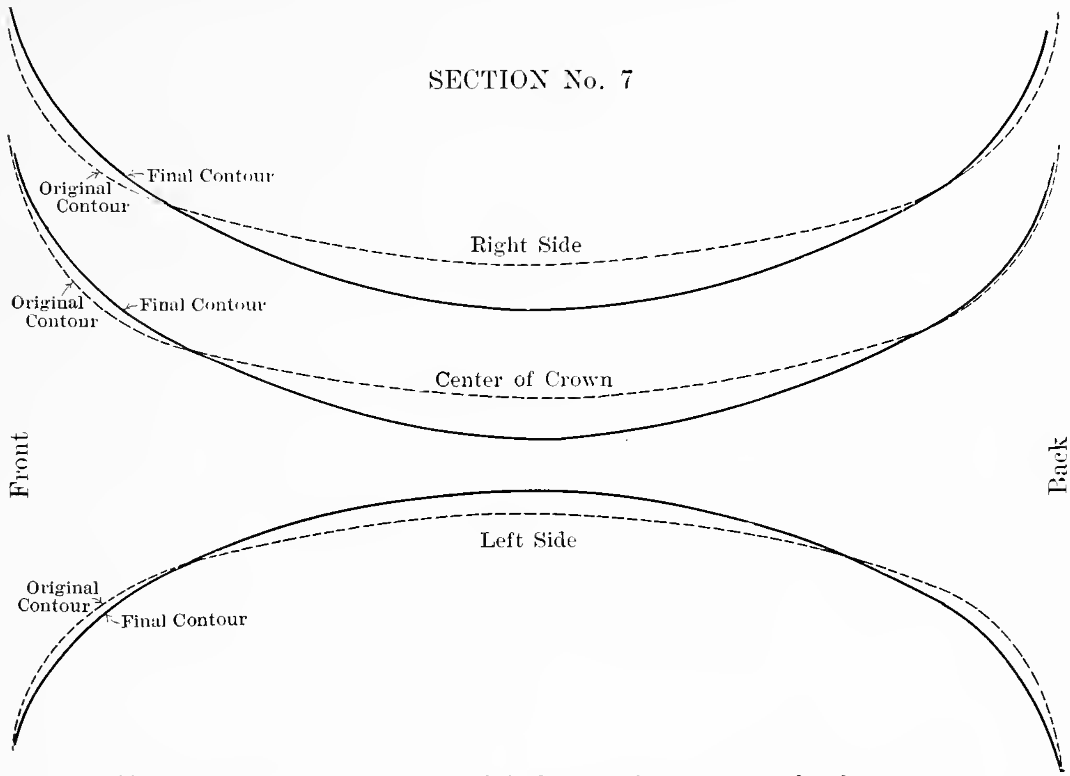


Fig. 91.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

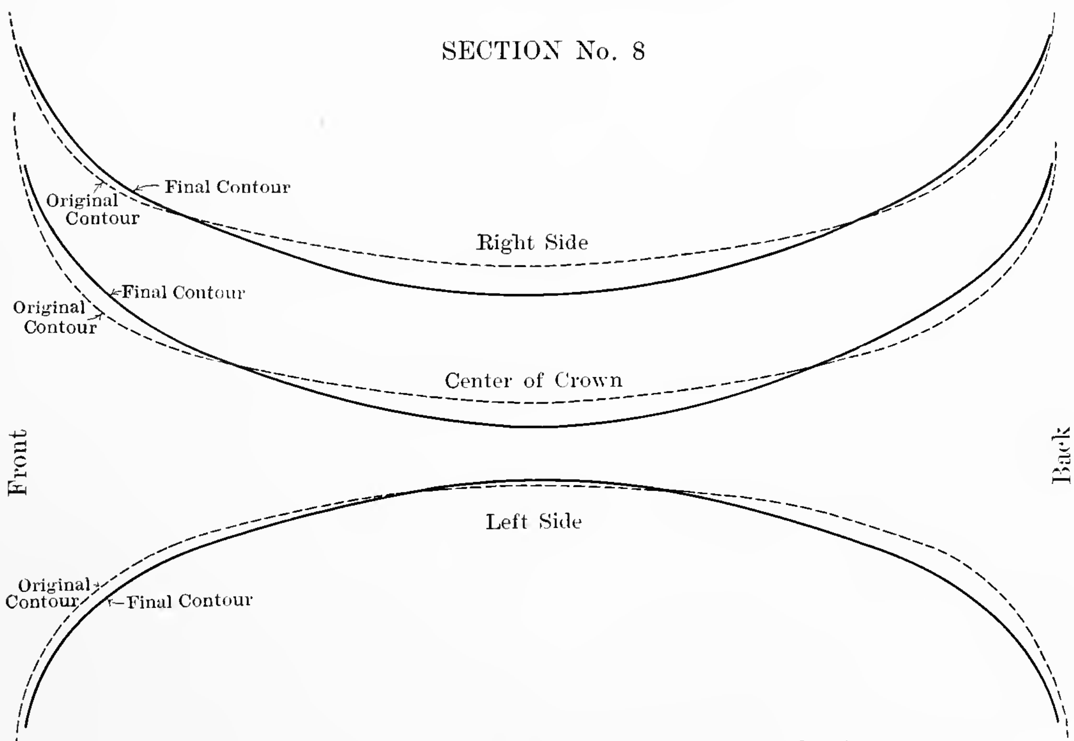


Fig. 92.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

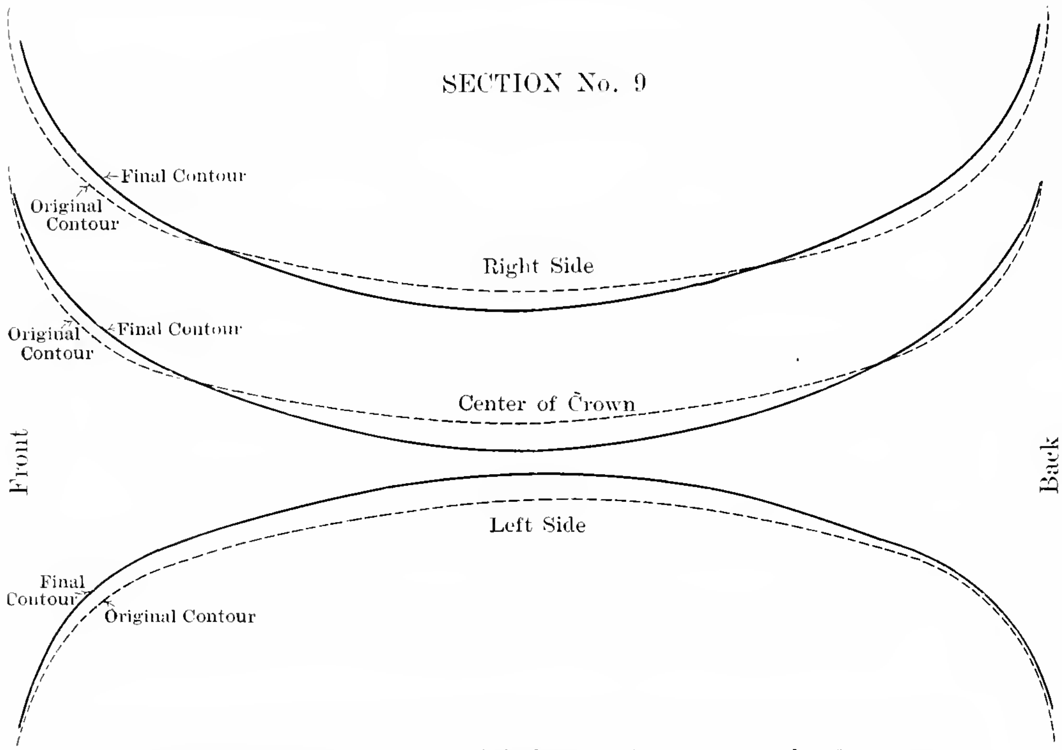


FIG. 93.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

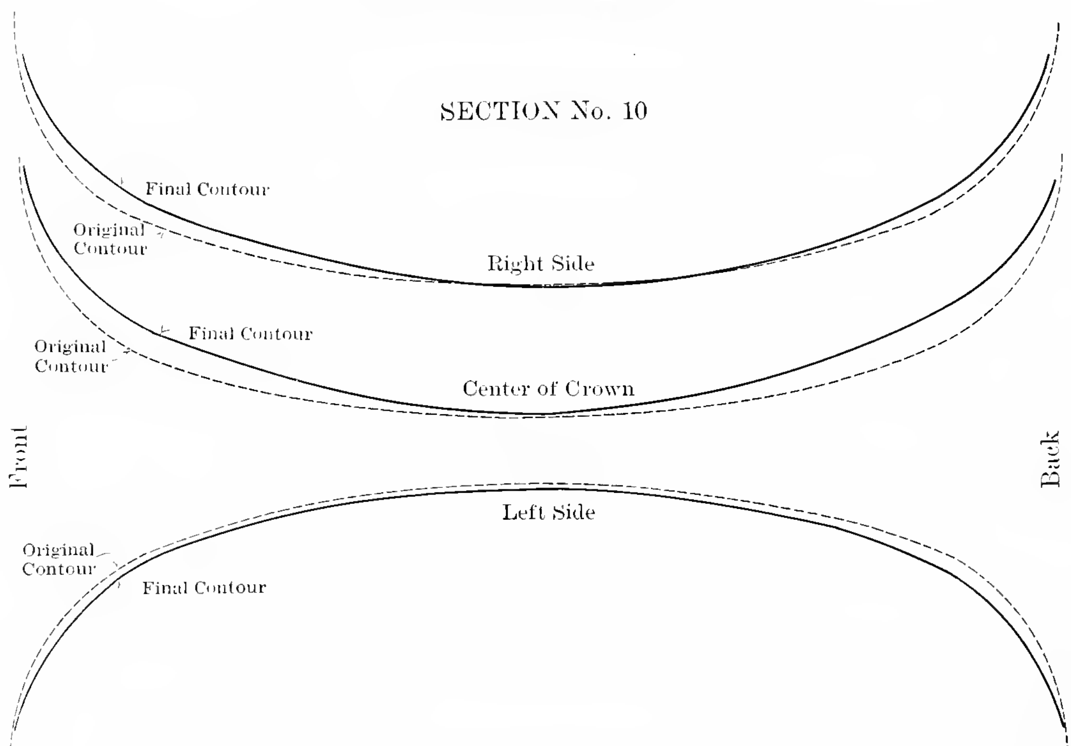


FIG. 94.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

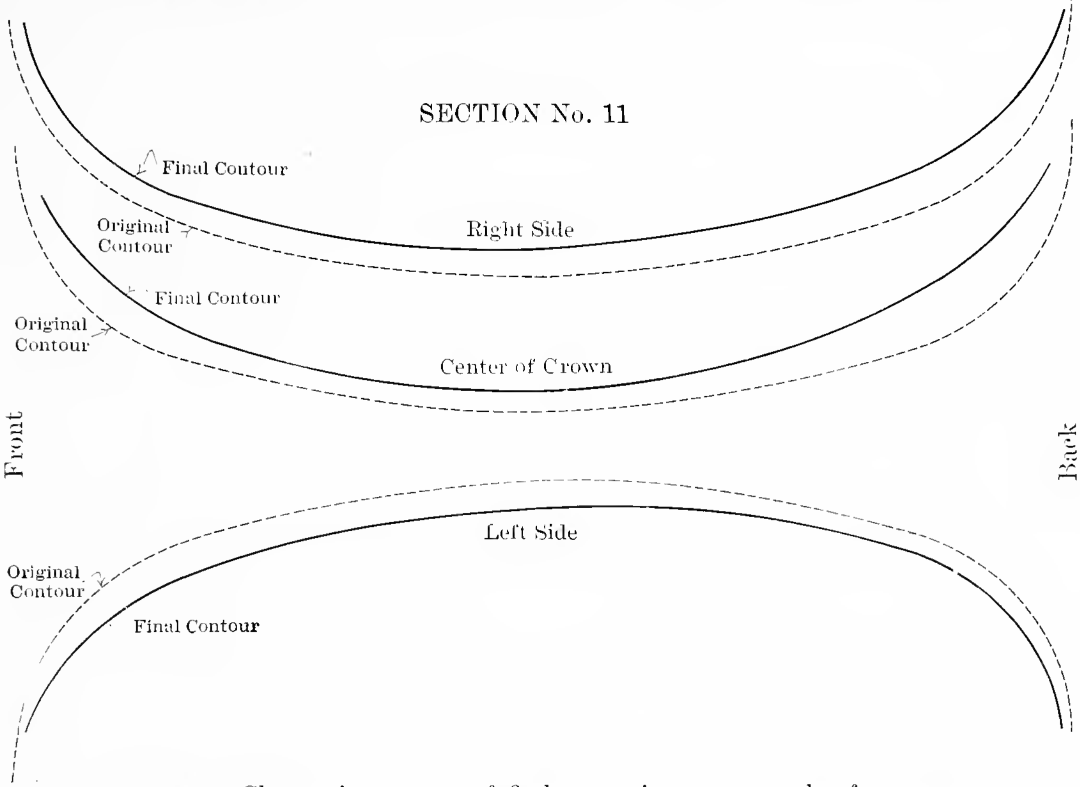


FIG. 95.—Change in contour of firebox sections as a result of exposure during low-water tests.

Illustrations are about six-tenths full size.

105. The radial-stay boiler failed under the low-water test. Its appearance at the moment of failure is shown by Fig. 96. The force of the explosion was sufficient to raise the rear of the boiler, to blow out the tile brick arch, to blow out the cast-iron pedestals, to disrupt the brick-work under the boiler, and to scatter fragments of all of these over an area a hundred feet or more in radius. The diagram (Fig. 97) and the photographs (Figs. 98 and 99) show well the distribution of débris. The boiler itself was lifted from its foundation and was moved forward a distance of about 8 inches, the rear swinging to the right, as shown by Figs. 100 and 101. As the front-end of the boiler slid forward on the support under the barrel, an extra heavy blow-off pipe was sheared.

106. The radial-stay boiler failed by the pocketing of a considerable section of the crown of the boiler (Fig. 102). This section embraces 188 crown-stays and stay-bolts. The button-headed stays failed by the stays breaking inside of the sheet and the flat-headed stays pulled through the sheet. The length of the damaged portion as measured longitudinally extends from the first row of stays, counting from the front-end of the firebox to the twenty-first row. In the first row the sheet pulled away from a single stay and in the twenty-first row from three stays. A plan of the crown-sheet and a profile of the pocket, the formation of which resulted in failure, are shown by Fig. 103. The sheet itself was found not to have ruptured or cracked, and, so far as could be determined, no

button-headed stay pulled through the sheet, though the holes in the sheet (Fig. 104) are in many cases considerably elongated in direction of the maximum movement of the plate. The contents of the boiler were discharged through the openings vacated by the stay-bolts, the aggregate area of which has been found to be approximately 186 square inches.

107. A considerable portion of the undisturbed area of the crown of the firebox was found to be mottled blue and black, giving evidence of some scaling from the effects of heat. The brightness of the color, however, had been affected by the discharge of steam from the firebox. The button heads of the undisturbed stays in the vicinity of the pocketed section showed the same variegated blue, black and white. This effect, however, was practically confined to the zone occupied by the button-headed rivets and to the forward two-thirds of that zone. There was a slight change in the superficial color of the plate between the eighth and ninth row of stays on the left-hand side of the boiler, suggesting that below the ninth row of stays the effect of overheating was nil.

Fig. 96.—The radial-stay boiler at the moment of failure. Escaping steam and water through the ruptured crown-sheet mingled with the smoke from the stack and formed a cloud several hundred feet in height completely enveloping its surroundings.

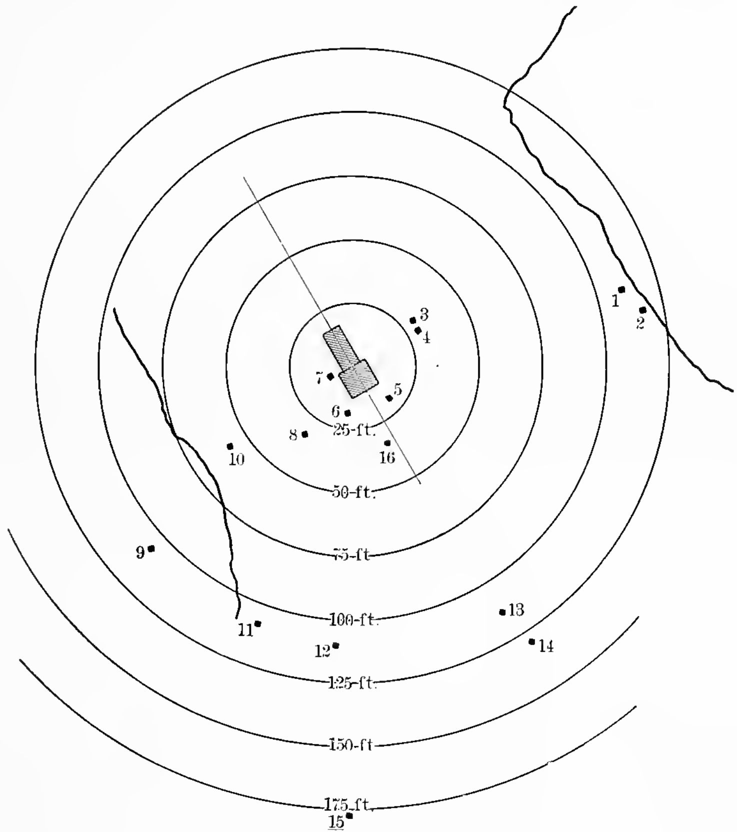
108. Both side-sheets with their staying were in perfect condition, no evidence of leaking stay-bolts appearing.

109. The door-sheet with its stays was found in perfect condition.

110. The tube-sheet was found in perfect form and the tubes appeared

to be as secure as when originally welded thereto. Only a few tubes, variously estimated from nine to eighteen in number, seemed from their color to have been involved by the overheating. No tube was found which had been sufficiently heated to sag. The very small portion of the tube-sheet which was overheated may be seen from Fig. 104.

111. The arch tubes had been forced somewhat downward by the



1. Piece of Arch Brick
2. Fragment of Brick from Side Wall
3. C. I. Pedestal
4. Iron Pipe Stand 7′–6″ long, 2″ E. H. flanges on ends
5. C. I. Pedestal
6. " " "
7. " " "
8. ½ Pig Iron (leaned against door)
9. Draft Door
10. " "
11. Fragment Arch Brick
12. " Brick
13. " "
14. " "
15. " "
16. Oil Boiler Piping

Fig. 97.—Diagram showing distribution of débris by explosion of radial-stay boiler.

discharge of steam from the crown-sheet (Fig. 105), and the right-hand tube had been distorted sufficiently to develop a leak in the tube-sheet.

112. The simple character of the failure of the radial-stay boiler permits our interest in the design and in the characteristics of the materials used in working out the design to be centered upon two things. These are the crown-sheet and the radial stays. The crown-sheet was manufactured by the Lukens Iron & Steel Company. A sample for test cut from this sheet and examined prior to the construction of the boiler gave the following characteristics:

FIG. 98.—Photograph showing the radial-stay boiler after the low-water test and the distribution of débris over a radius of 150 feet.

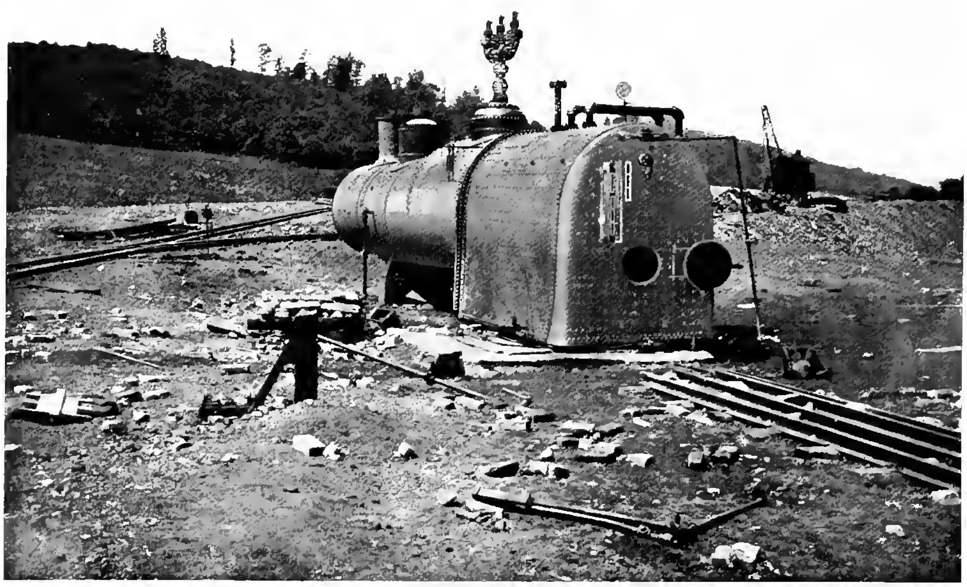


FIG. 99.—Another view of the radial-stay boiler after the low-water tests, showing effects of the explosion.

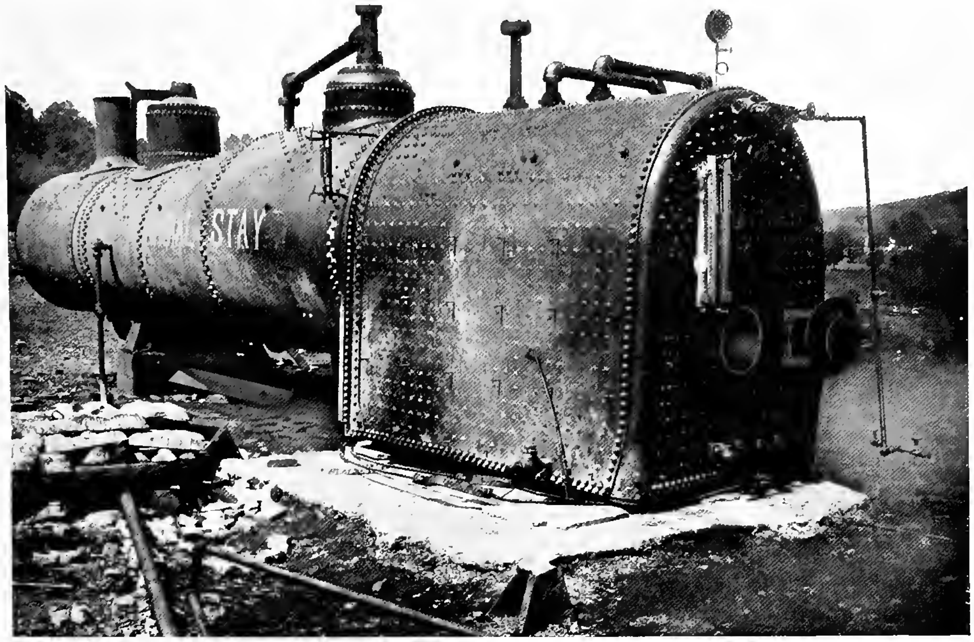


Fig. 100.—The radial-stay boiler after the low-water test. The explosion caused a forward movement of eight inches and a side movement of eighteen inches, the rear end swinging to the right on the front support as a pivot.

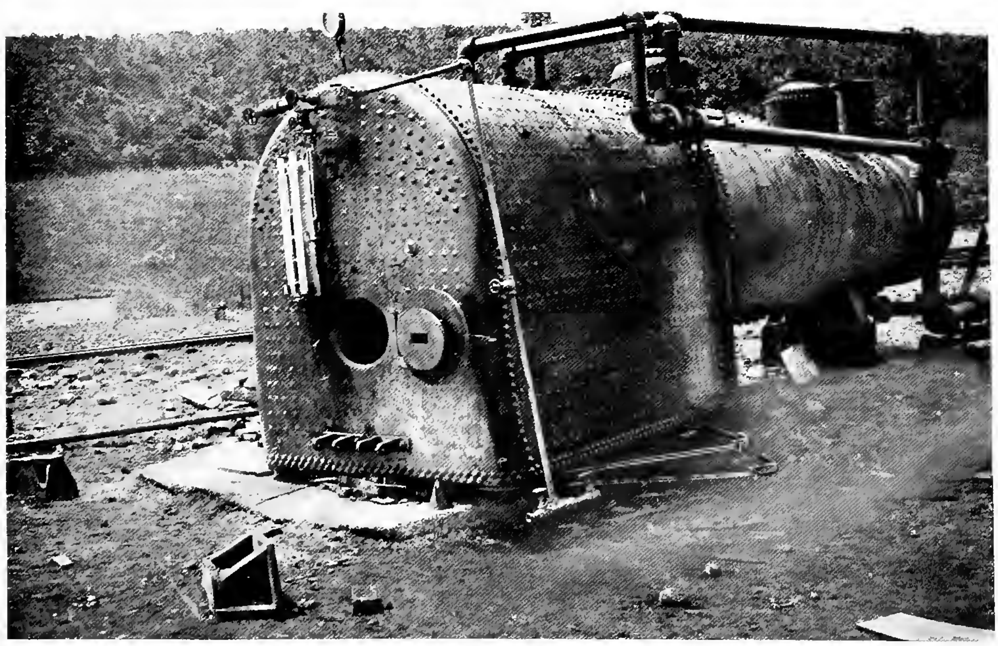


Fig. 101.—Another view of the radial-stay boiler after the low-water test, showing final position of boiler after its failure. In the foreground will be observed the supporting pedestals, one of which was broken.

Mark	N 1957
Ultimate strength, pounds per square inch	56,970
Elongation, per cent	25.00
Carbon, per cent	.16
Manganese, per cent	.42
Phosphorus, per cent	.02
Sulphur, per cent	.024

The fact that this sheet in coming down did not crack is in itself evidence of the high quality of the material.

113. The dimensions and design of the radial stays are shown by

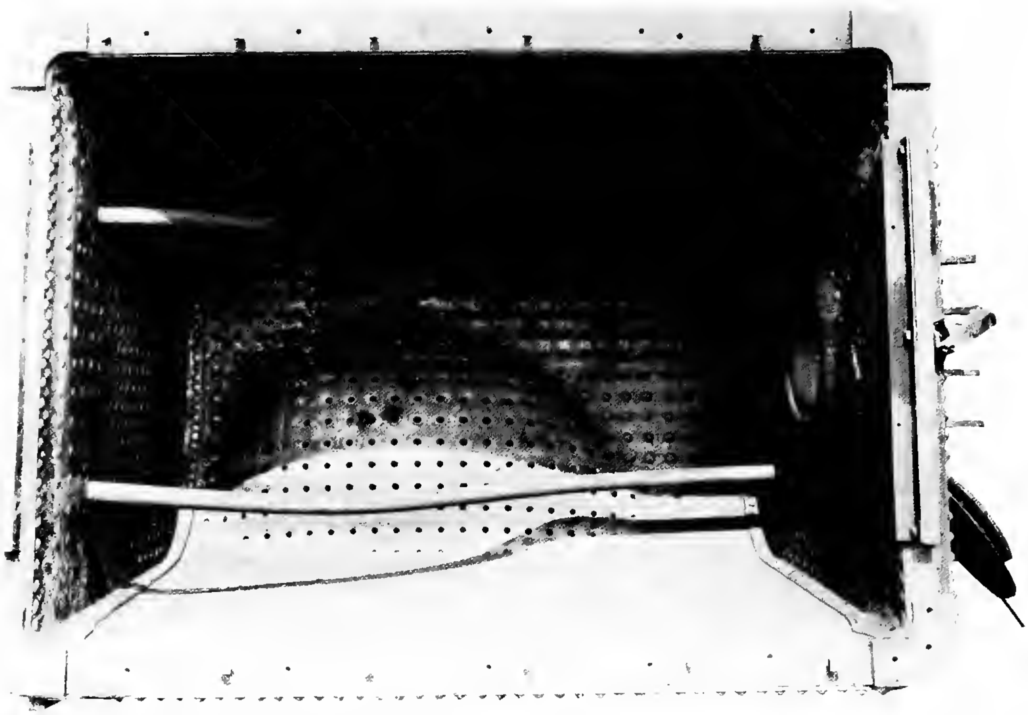


Fig. 102.—Photograph of radial-stay boiler, after low-water test, showing the failed crown-sheet. A large pocket was formed in the forward right side of the crown-sheet, the sheet pulling away from 188 crown-stays and stay-bolts. The button-head stays failed by heads breaking inside of sheet and the flat-headed stays pulled through the sheet.

Fig. 106. These stays were manufactured of Taylor stay-bolt iron and the record of the tests is as follows:

Mark	Taylor stay-bolt
Diameter	1.003
Area	.790
Breaking strength, pounds	38,200
Stress per square inch	48,400
Original length, inches	8.
Length after breaking, inches	10.72
Elongation, per cent	34.00

114. These statements will suffice to show that in the selection of materials and in working out the construction, the radial-stay boiler was not inferior to the highest standards prevailing in such matters. The fact

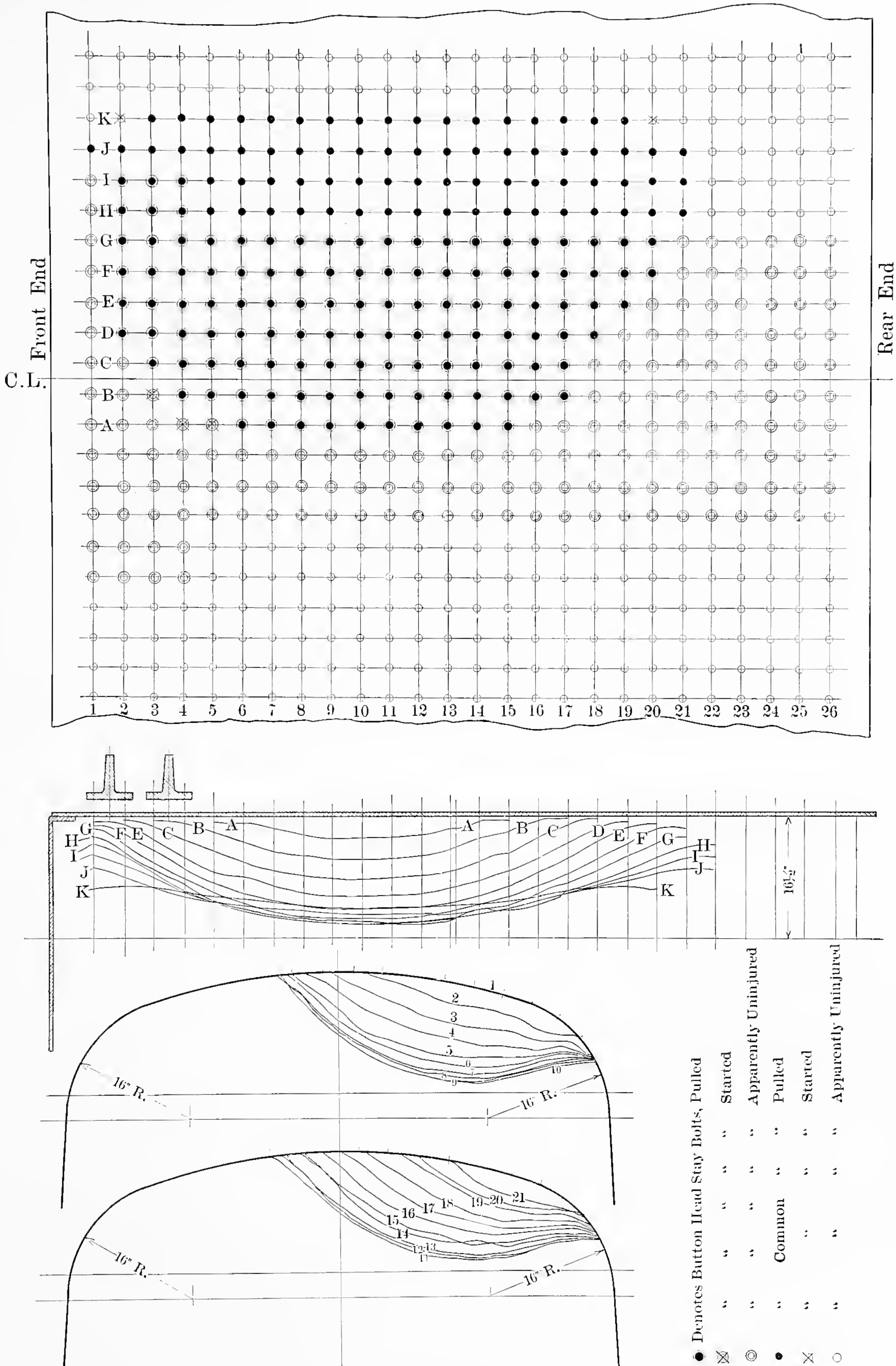


FIG. 103.—Plan and profiles of pocket in crown-sheet of radial-stay boiler.

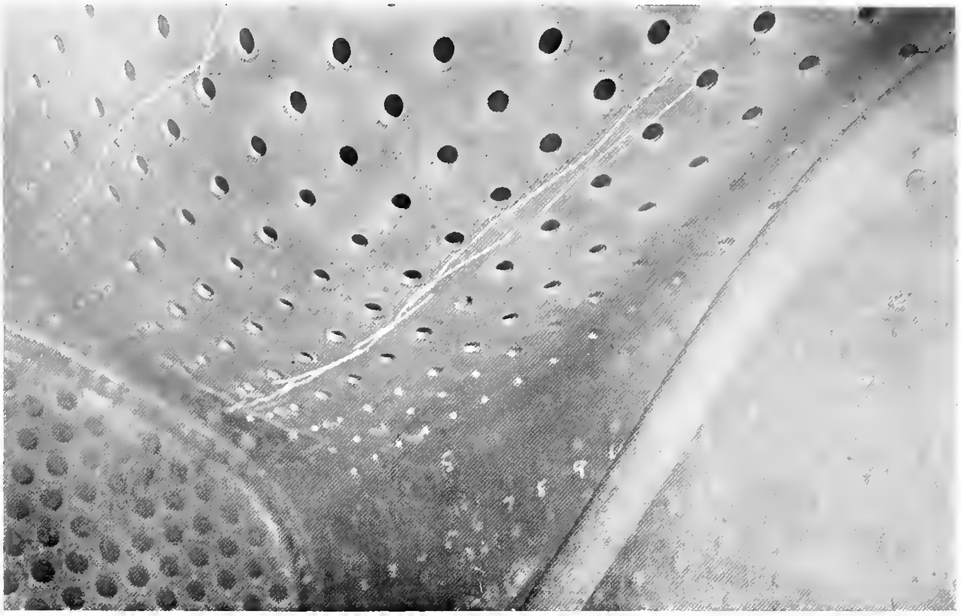


FIG. 104.—A close view of the pocket formed in crown-sheet of radial-stay boiler in the low-water tests. The sheet was not cracked or ruptured, and the tube, side and door-sheets were uninjured, all of which is conclusive evidence of the high quality of material and workmanship entering into the construction of this boiler.

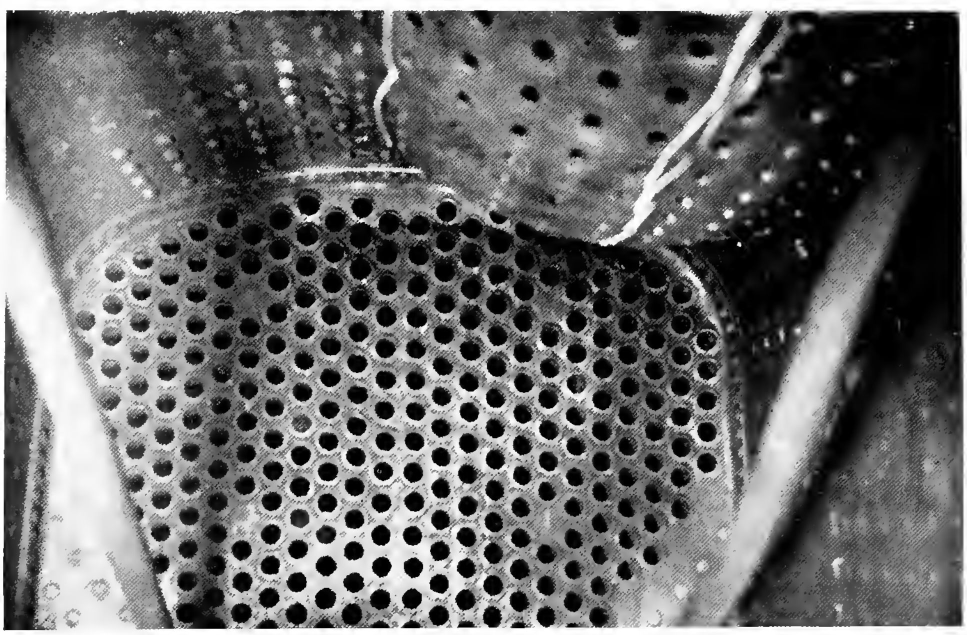


FIG. 105.—Photograph of radial-stay boiler after low-water test, showing pocket in crown-sheet. The arch tubes were disturbed and forced downward.

that the failure of the boiler was not more disastrous is to be accounted for in the superior character of the materials and workmanship employed in its construction.

115. The preceding description of the breaking down of the radial-stay firebox is significant in that it confirms the experience in practice on the road. The firebox tested was new; there was no accumulation of scale upon it. It had not been weakened by strains induced by long

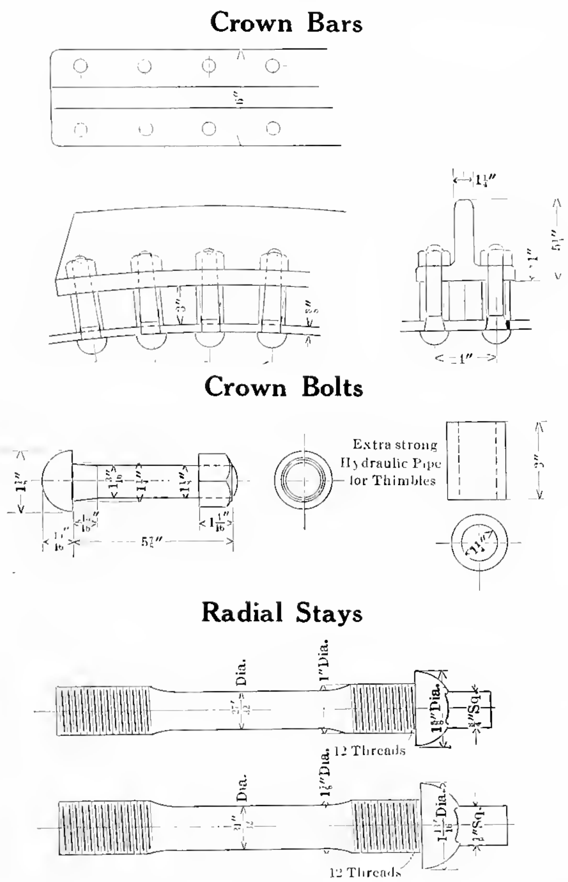


FIG. 106.—Crown bars, crown bolts and radial stays used in radial-stay boiler.

service, and it had every chance to present the maximum resistance to failure to be expected of that type of construction which it represents. The facts show, however, that when, through the receding of the water-level, the heated zone had extended downward sufficiently to include the upper portion of the crown and to take in only the upper rows of the tubes, this firebox, new and in perfect condition, possessing material advantage over the average radial-stay firebox in service, failed.

XII. Some Facts with Reference to the Circulation of Water in Locomotive Boilers

116. The motion of the water within a locomotive boiler in response to the energy transmitted to it in the form of heat, is known to have an important bearing on the up-keep and life of the boiler. It is known also that the water always rises from the heating-surface, and that upward currents thus stimulated must be compensated for by downward currents in other portions of the boiler. But the downward currents are secondary and are probably less stable and less direct than the initial currents which rise. In the complicated passages of a locomotive boiler, these secondary currents may take various directions and move with various velocities. Their strength and direction have been the subject of much loose speculation.

117. It has been urged, for example, that the presence of the stay-sheets which enter into the construction of the Jacobs-Shupert boiler, retards the circulation, and that they are, therefore, objectionable. Such an objection must be based upon the assumption that the stay-sheet is deficient in the openings it presents as channels for the fore and aft movement of water, and as these openings possess considerable area, it must be assumed also that the fore and aft currents are tremendously vigorous. Each of these assumptions is susceptible of rather careful examination.

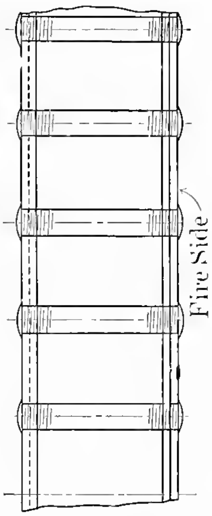
118. The stay-sheet of a Jacobs-Shupert boiler consists of a comparatively thin plate extending from the firebox to the shell of the boiler. From the mud-ring upward it is pierced at regular intervals with ports which are approximately 3 inches square. The bridge between the ports is normally 3.5 inches in width. Actual dimensions taken from the stay-sheet of the Jacobs-Shupert boiler which was tested, show the port location and area to be as follows:

Port No.	1,	center	2.0″	above mud-ring, area	11.0	sq. in.
" "	2,	"	9.0″	" " "	8.3	" "
" "	3,	"	15.5″	" " "	8.6	" "
" "	4,	"	22.0″	" " "	9.0	" "
" "	5,	"	28.5″	" " "	9.0	" "
" "	6,	"	35.0″	" " "	9.8	" "
" "	7,	"	41.5″	" " "	10.1	" "
" "	8,	"	48.0″	" " "	10.5	" "
" "	9,	"	54.5″	" " "	10.9	" "
" "	10,	"	62.5″	" " "	16.5	" "
" "	11,	"	68.7″	" " "	18.0	" "

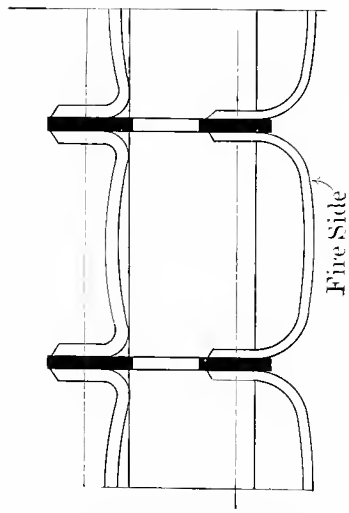
Portarea in water-leg of one side..........111.8 " "

Total area of ports in water space of boiler.....223.6 " "

These ports are entirely in the water space. Above them are others much larger which are in both the water and steam space. Assuming, then, that vigorous longitudinal currents are to be provided for in the water-leg of a locomotive boiler, the design in question provides a portage

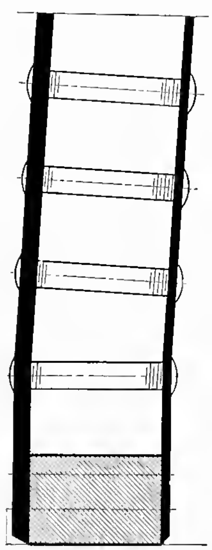


Radial-Stay Boiler.

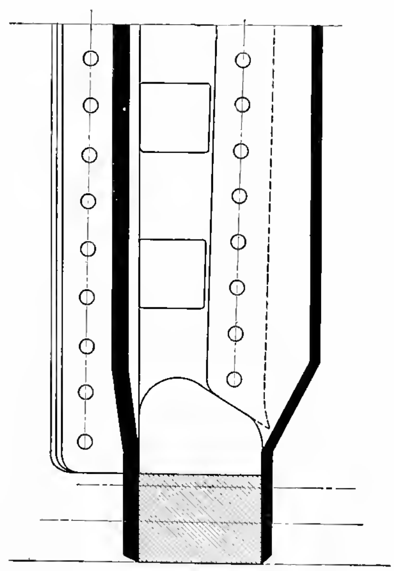


Jacobs-Shupert Boiler.

FIG. 107.—Horizontal section of water-leg of radial-stay and Jacobs-Shupert boilers.



Radial-Stay Boiler.



Jacobs-Shupert Boiler.

FIG. 108.—Vertical section of water-leg of radial-stay and Jacobs-Shupert boilers.

which, under a head as small as a hundredth of a foot, will suffice to pass a volume of water equal to that contained by the boiler in about 70 seconds.

119. A discussion of this question so far as it relates to the Jacobs-Shupert boiler, usually leads to comparisons between that type of boiler

and the radial-stay type, and the fact that in the radial-stay boiler there are obstructions to the fore and aft movement of water is often neglected. It may be that thickly-set stay-bolts impede the free fore and aft movement of water as much as stay-sheets. The clear space between the stay-bolts is greater than the port openings in the stay-sheets, but there are two and a quarter courses of stay-bolts where there is one stay-sheet. Fig. 107 presents a horizontal section of the water-leg of the two types of boilers. It shows in plan the obstructions which in each type of boiler impede the horizontal movement of water. Fig. 108 presents a similar comparison of vertical sections. While it is clear that the largest openings are in the radial-stay boiler, the differences are not great. This statement is emphasized by a comparison of photographic views of actual boilers (Figs. 38 and 41).

Fig. 109.—Crown-sheet of Jacobs-Shupert boiler, showing smooth, unobstructed, finely curved surface for ascending currents of water.

120. Thus far the argument has been addressed to those who insist upon the presence in the water-leg of the boiler of strong currents more or less horizontal in direction. Leaving this question for a moment, it will be of interest to observe the superior advantages presented by the Jacobs-Shupert boiler in facilitating the movement of water in a vertical direction. The water space about a Jacobs-Shupert firebox presents broad unobstructed channels, permitting freedom in the vertical movement of water, which have no counterpart in the stay-bolt boiler. Differences in dimensions are shown by the drawings presented as Fig. 107, which are to scale. A better understanding of the excellence of the surface over which the ascending currents sweep is given by Fig. 109 which is a view over the crown of a firebox section between two stay-sheets. In the radial-stay construction, an area similar to that shown would present two rows of stay-bolts extending out from the sheet which in the Jacobs-Shupert construction presents a smooth, unobstructed, finely curved surface.

121. The paucity of facts available concerning the movement of water about the firebox of a locomotive boiler led to an early determination on the part of the Jacobs-Shupert company to undertake an experimental study of the matter. In the development of its plans the well-known consulting engineer, Mr. George L. Fowler, was retained to conduct the proposed investigation. Mr. Fowler entered upon the work with enthusiasm. He skilfully devised a method of procedure and he designed and secured the construction of special apparatus which he afterward used at

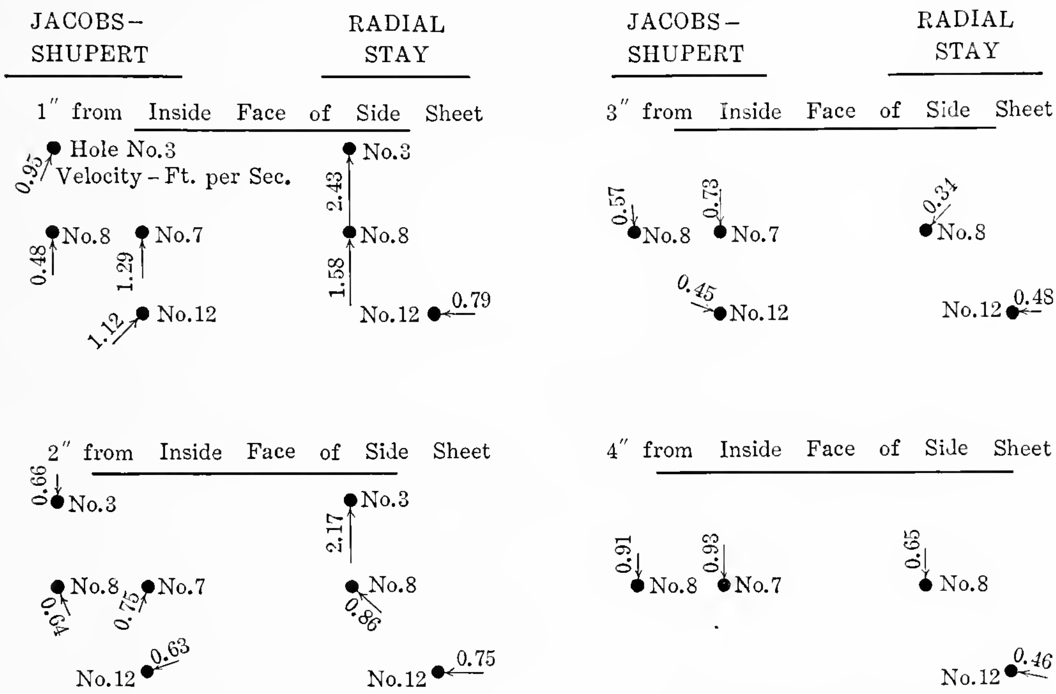


Fig. 110.—Diagram showing velocity of mixture in feet per second in different portions of water-leg.

the testing laboratory in Coatesville. Mr. Fowler assumed the responsibility for all that he undertook to do and is entitled to all the credit for the results achieved. What he did and how he did it is all described in his report, a brief summary of which is presented in the succeeding paragraphs. A complete transcript of Mr. Fowler's report concludes this chapter.

122. In preparation for Mr. Fowler's work, the water-leg, both of the Jacobs-Shupert boiler and of the radial-stay boiler, was drilled with fifteen holes regularly located at points chosen for exploration. The holes were filled when not in use by a 1-inch pipe plug (Fig. 112). It is to be regretted that in the time allowed for the work actual observations could only be taken at holes 3, 7, 8, and 12 of the Jacobs-Shupert boiler and at holes 3, 8, and 12 of the radial-stay boiler. By the methods employed by Mr. Fowler, and fully described by him in the report which follows, an exploring tube with an opening at right angles to its axis was connected with a suitable manometer gage. This tube was inserted at the point to be investigated. By turning the exploring tube on its axis and observing the indications of its gage, the direction of the flow could be ascertained. The tube was inserted through a stuffing-box and its initial end could be made to occupy any position along the line of its axis between the firebox sheet and the outside sheet of the boiler. The results as to direction are shown graphically, and as to velocity, both graphically and numerically, by Fig. 110. Concerning the inconsistencies

which are here apparent, Mr. Fowler calls attention to the fact that "the records of the angle of flow must not be taken as positive or fixed." The observations for direction of flow were not taken simultaneously with those for velocity. The fact is, as Mr. Fowler himself makes clear, that the work he has done is to be accepted only as the beginning of a solution of a very complicated problem.

123. It should be very clear from these statements that no useful result will follow an attempt to compare values obtained from the Jacobs-Shupert boiler with corresponding values from the radial-stay boiler. Neither as to direction nor velocity of flow are the values given absolute or comparable. Since all circulation is in response to the application of heat, the velocity of flow and for some points in the boiler, the direction also must depend upon the rate of power at which the boiler is operating. Since, also, the introduction of cold water must tend to suppress upward currents and stimulate downward currents, a full interpretation of any set of values must specify whether the injector is in operation or otherwise. Observations to determine the precise characteristics of the circulation, to possess comparative value, must be taken when all of these controlling conditions are maintained. Mr. Fowler's observations upon the radial-stay boiler were made during the progress of efficiency tests Nos. B—405—R, B—406—R, B—407—R, B—502—R, the results of which are elsewhere reported. His observations on the Jacobs-Shupert boiler were made after the boiler had been transferred to the site of the low-water tests, where it was especially operated for his work. The fact that Mr. Fowler makes no attempt to connect the results he observed with the rate of evaporation or with any other factor which could be accepted as a measure of the activity of the process within the boiler, is an indication that he regarded the data which it was possible for him to secure in the time allotted, as insufficient for such a purpose.

124. But notwithstanding the limitations which must be placed about them, Mr. Fowler's results constitute a distinct contribution to the sum of knowledge and are of tremendous significance. They show, for example, almost a complete absence of any fore and aft movement of the water. His conclusion upon this point is as follows:

"I think that if this matter were to be examined to a finality, it would be found that there is a regular slow movement from front to back, broken throughout the whole course by violent agitation and innumerable cross currents, but that in no place are these currents torrential nor is the steam movement itself very rapid."

That is, Mr. Fowler finds no evidence to show that the water at the bottom of the boiler is pushing backward and in the upper part forward. His observations seem to sustain the very rational assumption that enough water passes back from the barrel to the water-legs of the boiler to make good that which the firebox evaporates, and no more. Since the firebox

evaporates from 30 to 50 per cent. of the water handled by the boiler, a similar percentage of the total feed must, in the case of the Jacobs-Shupert boiler, find its way through the ports in the forward stay-sheet. Some of this water is evaporated before the second stay-sheet is reached. With the passage of each section, the backward flow diminishes until at the last stay-sheet only enough passes to supply that which the last section evaporates. Obviously, an aggregate port area of 1⅔ square feet is quite sufficient to pass from 30 to 50 per cent. of the water which the injector delivers through a 2-inch or a 2½-inch pipe.

125. The conclusion that the fore and aft movement of water in a locomotive boiler is no greater than is necessary to convey from the front of the boiler, where it is delivered, that portion of the feed which is to be evaporated by the heating-surface which is farther back, is amply confirmed by the experience gained in running the evaporative tests of Series A. It will be remembered that in these tests, both the Jacobs-Shupert boiler and the radial-stay boiler were fitted with a water-tight partition, absolutely closing off the barrel of the boiler from the firebox end. In this case, whatever circulation there was in the barrel could only involve barrel water, and whatever circulation there was in the firebox end could only involve the water of that end. Obviously, there was no chance here for the longitudinal movement of water, and yet, under these conditions, not the least difficulty was experienced with either boiler in working the rate of evaporation up to more than 10 pounds of water per foot of heating-surface per hour, that is, to a rate of power which upon the road would be regarded as normal.

126. All this should make clear the fact that the ports in the stay-sheets of the Jacobs-Shupert boiler have a very minor function to perform. Not only are they, as now designed, entirely sufficient, but the thermodynamic performance of the boiler could not suffer in any way if they were reduced to a small percentage of their present area.

127. The full report of Mr. George L. Fowler is as follows:

New York, June 12, 1912.

Prof. W. F. M. Goss, Urbana, Ill.

Dear Sir—In accordance with instructions received from you in your letter of October 3, 1911, I have made an investigation into the rapidity of the circulation of the mass of the liquid at a number of points of each of the two boilers which you have been testing for the Jacobs-Shupert Firebox Company.

The apparatus used for this purpose was designed to measure the velocity and direction of flow as well as the quality of the mass of the liquid at different points of the water-leg of the firebox. It is shown diagrammatically in the accompanying print. The principle of its operation is that of measuring the impact of the flow of the mass in the water-leg upon the mouth of a Pitot tube, by means of the elevation of a liquid heavier than water in a U-tube, and afterward determining the quality of the liquid, that is, the proportions of contained water and steam by means

of samples led off into a barrel calorimeter. The Pitot tubes were inserted in the firebox at the points where it was desired to make the measurements, and could be moved to and fro through suitable stuffing boxes so that the opening could be placed at any point between the two sheets. At the same time it was revolvable so as to be turned to face in any direction. The construction of the apparatus in detail was as follows:

The Pitot tube G (Fig. 111) was inserted in the water-leg and was connected by means of the flexible pipe C with the top of a water-glass F. From the bottom of the water-glass F another flexible tube B ran to the bottom of the water-glass E; while from the top of the water-glass E, a third flexible tube, A, ran to a point in the firebox below the water-line. The flexible pipe B and the two water-glasses formed a U-tube which was filled

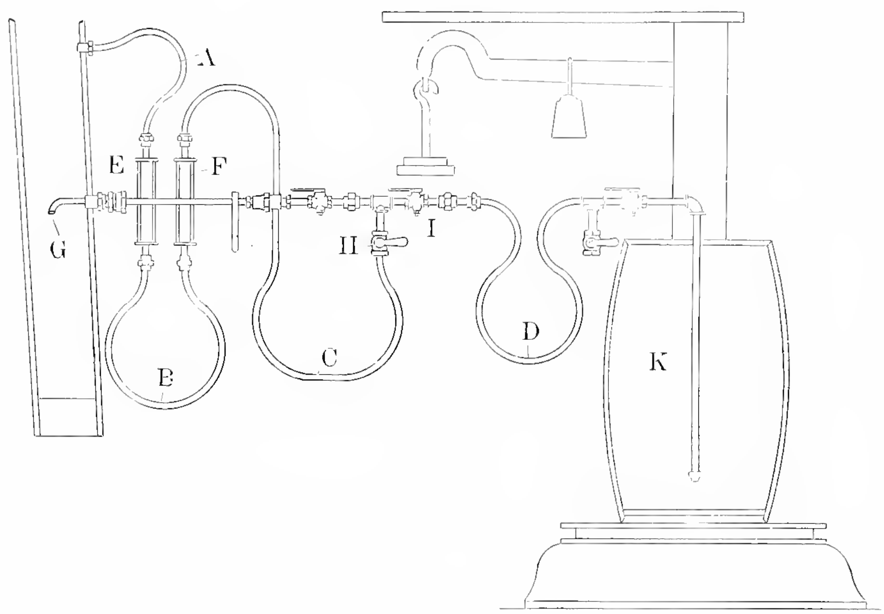


Fig. 111.—Apparatus for measuring boiler circulation.

to the center of the glasses with tetrachloride of carbon that was colored red and whose specific gravity is exactly 1.6. It was evident that, with connections to the boiler as shown, the liquid will stand at the same height in each of the two glasses so long as the pressure above the tetrachloride of carbon in each leg remains the same, but if the pressure on either leg exceeds that of the other, the tetrachloride in the leg of the higher pressure will be correspondingly depressed. This increase of pressure was secured by turning the Pitot tube, and when it faced directly into the stream, it would produce the greatest pressure at the top of the glass F, with a corresponding depression of the tetrachloride in that leg.

For convenience of entering the boiler fifteen holes were drilled in the side of the firebox. They were in three rows, five in a row and numbered, for the sake of identification, as shown in the accompanying print Fig. 112. The Pitot tubes were used; those holes not occupied being plugged.

After a reading had been taken, the valve H was closed and the valve I opened. This cut the pressure off from the top of the water-glass F, and allowed the mixture of steam and water entering the Pitot tube to flow into the water partially filling the barrel calorimeter K, when from the temperature ranges before and after the admission of the liquid from the boiler together with the pressure existing at the time as read from the steam gage, it was possible to determine the percentage of steam and water entering into the mixture as it existed at the mouth of the Pitot tube in the water-leg. From this the specific gravity of the mass could be calculated.

Then with the head produced by the difference in the levels of the tetrachloride of carbon and the specific gravity of the liquid whose impact caused that difference of level, the velocity of the liquid can be calculated. This is the method followed in all of my observations and which are tabulated on the accompanying sheets. (Tables 6 and 7.)

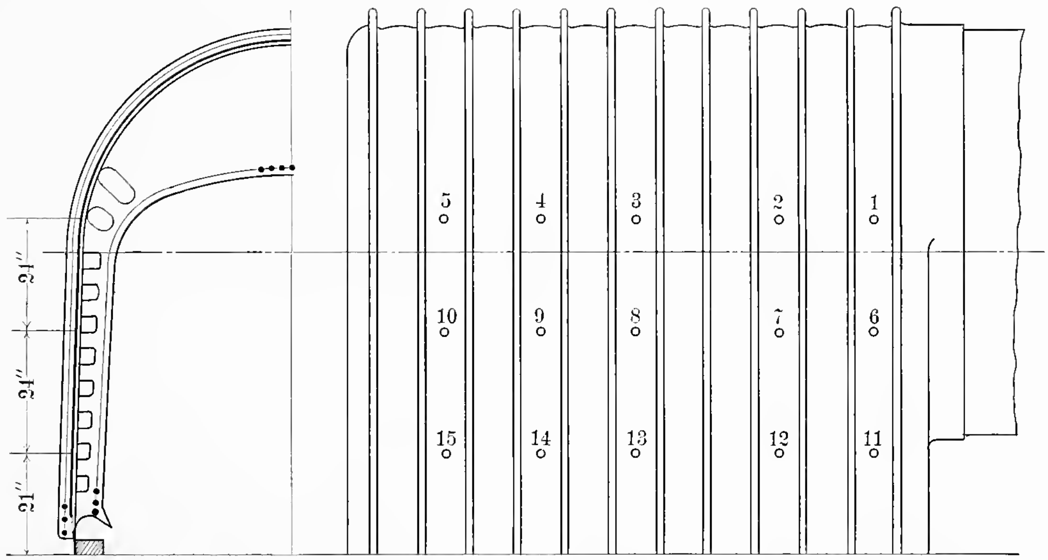


FIG. 112.—Side elevation and section of firebox showing location of holes for circulation tests.

The heat (B. t. u.) given is for that above 32 degrees Fahr. The column headed "Angle of Flow," indicates the observed angle at which the mass was moving at the time of the observation. It is measured in the direction of the movement of the hands of a watch starting with 0 for the vertical downward movement. Then 90 degrees would be horizontally from the front to the back; 180 degrees vertically upward, and 270 degrees horizontally from the rear to the front.

The "Specific Gravity of the Mass" denotes the specific gravity of the combined mass of steam and water.

The "Velocity of the Mass" is the velocity which a mass of the corresponding specific gravity would have to have in order, by its impact on the mouth of the Pitot tube, to cause the difference in the level of the tetrachloride as observed.

The "Velocity of the Steam," given in the last column, is the velocity that steam of the pressure existing in the boiler at the time of the observation would have to have in order to cause the observed difference in the levels of the tetrachloride.

These velocities are calculated on the basis of the elevation of a mass whose specific gravity is 0.6, for this reason. The specific gravity of the tetrachloride is 1.6. The 1 is balanced by the superincumbent weight of water in each leg of the U-tube, leaving only the .6 to be moved by the impact on the Pitot tube.

In handling the apparatus and making the observations here recorded, the differences in level of the tetrachloride were first observed. Then water and steam were blown through the piping, leading to the calorimeter, sufficient to heat it, after which it was turned into the barrel for the measurement of its heat values.

The records of the angles of flow must not be taken as positive and fixed. The figures given are for the approximate average inclination of the flow. As a matter of fact it shows every evidence of constant variation, sometimes through angles approximately 45 degrees for the higher velocities, and this together with other general indications have led me to the opinion that there is much agitation in a boiler, with comparatively little circulation or progressive movement of the water. I think that if the matter were to be examined to a finality it would be found that there is a regular slow movement from front to back, broken throughout the whole course by violent agitation, and innumerable cross currents, but that in no place are these currents torrential nor is the steam movement itself very rapid, while in some places there is a true circulation, that is, the water follows a definite path returning to a previous position. An example of this is found in the tests at hole 8 of the radial-stay boiler on June 4. At one inch from the inside sheet there was an upward flow of 1.71 feet per second; at two inches the flow was still nearly vertical; at three inches there was a neutral point at which no movement could be detected; while, at four inches or near the outer sheet, there was a vertical movement downward. The same thing is observable with the Jacobs-Shupert firebox at holes 7 and 8, but without the indication of a neutral zone devoid of flow.

There are some peculiarities in the observations that I cannot attempt to account for because of the limited data. For example, in the observation at hole 12 of the radial-stay boiler, the three records of the third, show a constantly increasing percentage of steam in the mixture from the inner sheet to the outer. This is checked by the observations on the fourth, except that the one at four inches from the sheet, which is farther out than that of the third, shows a falling off as the outer sheet is approached. This same condition, though not so markedly, appears in the Jacobs-Shupert boiler at hole 7.

As for the general character of the water movement, there is, in the radial-stay boiler an entire absence, so far as my observations went, of eddy or reverse currents. The movement is either vertical or back from front to rear, whereas in the Jacobs-Shupert firebox, with the general movement the same, there was one hole where the movement was from the rear to the front, evidently due to eddies set up by the stay-plates.

In calculating these velocities corresponding to the heights, I have taken it that these heights or differences of level vary as the impinging mass and that the squares of the velocities vary inversely as the mass.

You will observe that the percentages of steam are less in the Jacobs-Shupert boiler than in the radial-stay. From the dates you can determine the probable rates of evaporation in the radial-stay, from your

DETAILS OF OBSERVATIONS OF CIRCULATION IN RADIAL-STAY BOILER

Table 6

DATE	TIME	NO. OF HOLE	DISTANCE FROM INSIDE SHEET, INCHES	HEIGHT OF LIQUID IN U-TUBE, INCHES	WATER		CALORIMETER		FROM BOILER			ANGLE OF FLOW	BOILER PRESSURE LBS.	PERCENTAGE OF STEAM IN MASS	SPECIFIC GRAVITY OF MASS	VELOCITY OF MASS IN FT. PER SECOND	VELOCITY OF STEAM IN FT. PER SECOND
					WEIGHT LBS.	TEMP. FAHR.	WEIGHT LBS.	TEMP. FAHR.	WEIGHT OF WATER LBS.	TOTAL B. T. U.	B. T. U. PER LB. WATER						
June 3	A.M.	8	1	1	400.5	78	440.0	114	39.5	19,478	493	180	200	15.7	.850	1.92	20.65
"	"	8	2	1/8	431.5	82	460.0	106	29.5	13,940	472	147	220	12.4	.895	.67	7.00
"	"	12	1	1/4	404.0	82	448.0	112½	44.0	18,064	411	90	190	6.4	.928	.93	10.49
"	"	12	2½	1/8	416.0	83	454.0	114	38.0	17,950	473	90	185	14.0	.847	.69	7.51
"	"	8	3½	1/8	394.5	84½	445.0	129	50.5	25,105	497	55	220	15.5	.873	.68	7.00
"	2.54 P.M.	8	1	3/8	332.0	86	376.5	110	44.5	13,842	405	180	180	6.0	.980	1.10	13.17
"	3.26 "	8	2	3/8	316.5	88	356.0	118	39.5	15,104	382	152	170	3.7	.967	1.11	13.50
June 4	9.13 A.M.	8	1	7/8	358.0	78	386.5	100½	28.5	11,418	400	180	205	4.5	.954	1.71	19.00
"	10.33 "	12	1	1/8	376.0	83	416.5	112½	40.5	16,418	405	90	205	5.1	.949	.65	7.19
"	11.00 "	12	2	3/32	341.0	86	396.0	128	55.0	22,572	410	90	205	5.7	.943	.80	8.79
"	11.20 "	12	3	1/16	348.0	88	400.0	128½	52.0	22,024	435	90	210	8.4	.921	.48	5.02
"	11.44 "	12	4	1/16	336.0	88	388.0	128½	52.0	21,538	414	93	210	5.9	.943	.46	5.02
"	1.30 P.M.	8	2	5/16	339.5	86	388.0	123	48.5	19,594	404	175	220	4.3	.980	.79	11.12
"	1.54 "	8	3	0	342.0	88	386.0	122½	44.0	18,245	415	...	215	5.8	.947	.00	0.00
"	2.12 "	8	4	1/8	341.5	88	383.5	122	42.0	17,743	422	0	205	7.1	.930	.65	19.00
June 5	8.45 A.M.	3	1	1½–2	318.0	76	350.0	106	32.0	13,316	416	180	215	6.0	.944	2.25 2.60	24.35 28.12
"	9.41 "	3	2	1¼–1½	320.0	82	347.5	104	27.5	10,375	377	180	155	4.2	.935	2.07 2.26	25.67 28.13

DETAILS OF OBSERVATIONS OF CIRCULATION IN JACOBS-SHUPERT BOILER

Table 7

DATE	TIME	NO. OF HOLE	DISTANCE FROM INSIDE SHEET, INCHES	HEIGHT OF LIQUID IN U-TUBE, INCHES	WATER		CALORIMETER		FROM BOILER			ANGLE OF FLOW	BOILER PRESSURE LBS.	PERCENTAGE OF STEAM IN MASS	SPECIFIC GRAVITY OF MASS	VELOCITY OF MASS IN FT. PER SECOND	VELOCITY OF STEAM IN FT. PER SECOND
					WEIGHT LBS.	TEMP. FAHR.	WEIGHT LBS.	TEMP. FAHR.	WEIGHT OF WATER LBS.	TOTAL B. T. U	B. T. U. PER LB. WATER						
June 7	3.50 P.M.	8	1	1/4	331.0	77	373.0	110	42.0	18,926	451	180	170	12.8	.843	.48	11.02
"	4.15 "	8	2	1/8	299.0	84	328.0	108½	29.0	11,032	380	160	205	2.1	.976	.64	7.18
"	4.30 "	8	3	3/32	328.0	76	364.5	108	36.5	14,876	408	0	202	5.8	.940	.57	5.05
"	4.40 "	8	4	1/4	359.5	77½	402.0	109	42.5	16,530	389	0	210	2.5	.975	.91	10.09
"	5.10 "	12	1	3/8	344.0	81	381.5	112	37.5	15,501	413	225	225	5.2	.954	1.12	11.94
"	5.30 "	12	2	1/8	343.5	78	398.0	115	54.5	19,760	363	75	125	4.4	.912	.63	8.93
"	5.45 "	12	3	1/16	322.5	84	370.0	123	47.5	19,370	408	315	225	4.5	.961	.45	4.87
June 8	10.45 A.M.	7	1	1/2	344.0	65	406.0	116	62.0	24,898	401	180	220	3.9	.964	1.29	13.32
"	11.05 "	7	2	3/16	350.0	84	395.0	118½	45.0	18,307	418	190	220	5.9	.947	.79	8.53
"	11.23 "	7	3	5/32	349.5	89	386.0	116	36.5	14,583	400	0	215	4.0	.962	.73	7.87
"	12.00 "	7	4	1/4	338.5	86½	381.5	120	43.0	17,467	406	0	200	4.5	.952	.93	14.60
"	12.22 "	3	1	1/4	352.0	85	384.5	113	32.5	14,211	437	190	190	9.5	.897	.95	14.85
"	12.45 "	3	2	1/8	344.5	94	374.5	118	30.0	12,708	423	0	190	7.8	.913	.66	10.89
"	....	7	4	3/16	....	....	....	....	....	....	....	0	....	....	....	....	....

other tests with the Jacobs-Shupert the evaporation is estimated to have been about 12 pounds per square foot of heating surface per hour. And the boiler was being fed with water at a temperature of about 70 degrees Fahr. The rate of movement, too, was more rapid with the radial-stay than with the Jacobs-Shupert, but in both cases the movement was so slow that no criticism can be offered as to the checking of the flow by the stay plates of the Jacobs-Shupert firebox. Evidently, from the rate of flow and the percentage of steam contained in the water, there was ample opportunity for the water to come back and completely fill the leg.

Incidental to this, I observed that a change in the rate of steam flow through the exhausting pipes would have its effect on the velocity of the currents in the water-leg of the firebox. The opening of the safety-valve, for example, would increase the speed at once. While when the pressure was being raised, the water seemed quite stagnant.

In order to ascertain the likelihood of there being a straight flow of cold water from the front to the rear over the top of the foundation ring, a thermometer was placed at the back lower corner of the Jacobs-Shupert firebox on the eighth, when being driven as already indicated and using feed water at a temperature of about 70 degrees Fahr. When the boiler was at work under 215 pounds' pressure the observed temperature at this point was 380 degrees Fahr., or only 13 degrees below the boiling point at that pressure. This indicating either a circulation through hot portions of the boiler before reaching the back end of the water-leg, or an agitation of the water en route and its mingling with quantities of steam or hot water by which its temperature was raised.

The tests cannot be regarded as conclusive because of their meagerness, but they indicate that neither the water nor steam velocities of a locomotive firebox are high, and that the opening in the stay-plates of the Jacobs-Shupert firebox are quite sufficient to admit the water in ample quantities to all parts of the water-leg.

Finally I wish to suggest that many of the seeming inconsistencies of these observations may be attributed to the interval of time between them. This ran for fifteen minutes to forty-five minutes in which there was ample time and opportunity for such changes to occur in direction of flow and rate of evaporation as to fully account for the actual changes observed.

Respectfully submitted,

(Signed) Geo. L. Fowler.

XIII. Experimental Methods and Observed and Computed Results

128. There is presented in this chapter as Tables 8 to 30, inclusive, the full exhibit of observed and calculated results derived from the evaporative tests. Series A (Tables 8 to 19) consists of 21 tests, and for each of these the water and steam record is presented separately for the barrel and the firebox end. Series B (Tables 20 to 30) consists of 19 tests. This gives a total of 40 tests reported. The facts associated with these tests are presented under 125 headings. Each of these column headings bears a number, and throughout the text, whenever tables are used, any given column number always refers to the same heading.

129. In general the methods employed have been those outlined by the code for conducting boiler trials of the American Society of Mechanical Engineers. The observed data tabulated have been corrected in so far as necessary in accordance with calibrations of the instruments in question. The Steam Tables of Marks and Davis have been employed.

130. That no one may be in doubt as to the significance of any item given, the tables are preceded by concise explanations of the manner in which the values of each column were obtained. This is as follows:

Table 8, Tests Series A, and Table 20, Tests Series B

General Conditions

131. Column 1. Designation of Test.—This column appears upon each of the tables as a cross reference. The first term of this designation indicates the series to which the test belongs, the second, the number given the test, and the third, the boiler upon which the test was made. Thus, the designation for the first test reported upon Table 8 is A–1–J, which indicates that this test belongs to Series A, has been given the laboratory number 1 and was conducted upon the Jacobs-Shupert boiler.

Column 2. Date of Test.

Column 3. Duration of Test, Hours.—In general it was sought to have the duration of oil-fired tests such as would result in the consumption of from 4,000 to 6,000 pounds of oil. In like manner it was sought to have all tests during which coal was used of such duration that approximately 10,000 pounds of coal would be burned. For the low and medium power tests, it will be noted that from 8,000 to 11,000 pounds of coal were burned. For the high power tests, it was found impossible for a single fireman to handle to the best advantage more than 6,000 or 7,000 pounds of coal at the necessary rate of firing. On this account it was deemed

advisable to limit the tests to such a length as would permit one fireman to work through an entire test. For high power test No. B–209–R, only 3,672 pounds of coal were fired. This test was closed at the end of 40 minutes on account of injector trouble.

Column 4. Power.—This column will be of service in indicating approximately the load carried by the boiler. For Series A, the terms "Low," "Medium," and "High" indicate approximately an equivalent evaporation per square foot of heating-surface for the entire boiler per hour of 4, 7, and 10 pounds, respectively. In like manner for Series B the same terms indicate rates of 5, 10, and 15 pounds of equivalent evaporation per square foot of heating-surface per hour.

Column 5. Furnace.—This column appears only upon Table 20 relative to Series B, indicating whether or not the firebox was equipped with a brick arch. During Series A the fireboxes were without arches during all tests. A description of the arches as installed during Series B will be found in paragraph 74, page 77.

Column 6. Barometric Pressure, Pounds per Square Inch.

Column 7. Boiler Pressure, Gage, Pounds per Square Inch.—During Series A the boiler pressure was recorded both for the firebox end and the barrel end of the boiler. In all tests, however, the average values for the two portions of the boiler were found to be the same and are so recorded. The location of the gages and arrangement of piping showing the method by which the pressure was equalized between the two ends of the boiler are shown in Figs. 47 and 48, pages 58 and 59.

Column 8. Temperature of the Laboratory, Degrees Fahr., is the average of observations taken upon an ordinary dry-bulb thermometer at 10-minute intervals.

Column 9. Temperature of Laboratory by Wet-Bulb Thermometer, Degrees Fahr., is the average of observations taken upon a stationary wet-bulb thermometer at 10-minute intervals.

Column 10. Temperature of Outside Air, Degrees Fahr.

Column 11. Temperature of Smoke-Box Gases, Degrees Fahr., was determined by means of thermo-couples, the location of which is indicated in Fig. 49, page 59.

Column 12. Draft Back of Diaphragm, Inches of Water.

Column 13. Draft Front of Diaphragm, Inches of Water.—For the high power tests of Series B mercury manometers were used to determine the draft in front of the diaphragm. In all other cases water manometers were used in making draft determinations. Fig. 52, page 61, shows the location of draft gages in connection with one of the boilers.

Table 9, Tests Series A, and Table 21, Tests Series B

Fuel

132. Column 14. Total Oil Burned, Pounds.—The oil used was obtained from the Sun Company, Marcus Hook, Pennsylvania, and has been referred to as "close cut." It is stated that it had been specially treated for the removal of sulphur. Its analysis is given in Table 16, page 152. Oil was delivered to a weighing tank set upon platform scales from which it passed to a calibrated storage tank and thence by gravity to the oil burner. Figs. 50 and 51, page 60, show the arrangement of the oil tanks. The amount of oil burned, as shown by the calibration of the storage tank, was recorded every 20 minutes.

Column 15. Oil per Hour, Pounds = column 14 ÷ column 3.

Column 16. Kind of Coal.—Two kinds of coal were used during the tests, Scalp-Level and Dundon Gas coal. The Scalp-Level coal was mined in Cambria County, Pennsylvania, and may be described as a short flame coal. The Dundon Gas coal, a long flame coal, was mined at Widen, West Virginia, on the line between Clay and Nicholas counties. For those tests marked "hand-picked" lumps from 2 to 3 inches in diameter and larger were used, the larger lumps being broken to size suitable for firing. For test No. B–406–R coal which had been left from previous tests was run over a ½-inch screen, thus removing a large portion of the very fine coal which would otherwise have been unduly large for this particular test. Upon Tables 15 and 26, pages 148 and 159, will be found chemical analyses of the coal employed, and upon Tables 17 and 28, pages 150 and 161, will be found their calorific values.

Column 17. Coal as Fired, Total, Pounds.—All coal fired was weighed on platform scales and distributed to the storage bins, two in number. The fireman drew his supply from one bin for the check period of twenty minutes. At the end of that time any coal remaining was weighed back and the bin credited with same. The supply was then drawn from the remaining bin for the next check period. In this way each bin was in service every alternate twenty minutes. Fig. 53, page 61, shows the arrangement of scales for weighing coal and ash. As each coal barrow was brought into the building a shovel of coal was taken from it and deposited in a container. At the end of the test this sample was mixed and quartered, one-quarter being placed in a shallow iron pan and covered. Weighings of this sample before and after drying gave determinations as to accidental moisture. After the accidental moisture determination had been made the sample was again mixed, crushed and quartered until a suitable sized sample was obtained which was placed in an air-tight container and forwarded to the chemical laboratory.

Column 18. Coal as Fired per Hour, Pounds, = column 17 ÷ column 3.

Column 19. Coal as Fired per Square Foot of Grate per Hour, Pounds, = column 18 ÷ grate surface, square feet.

Column 20. Moisture Free Coal, Total, Pounds, = column 17 × (1 − (column 80 ÷ 100)).

Column 21. Moisture Free Coal per Hour, Pounds, = column 20 ÷ column 3.

Column 22. Moisture Free Coal per Square Foot of Grate per Hour, Pounds, = column 21 ÷ grate surface, square feet.

Table 10, Tests Series A, and Table 22, Tests Series B

Fuel (Continued)

133. Column 23. Total Ash, Pounds.—The ashes were drawn from the ash-pan from time to time as the test progressed and weighed at the conclusion of the test. A shovel full of ashes was taken from each barrow load after being weighed and placed in a container. This gross sample was then mixed, crushed, and quartered until a suitable sized sample remained which was forwarded to the chemical laboratory for analysis.

Column 24. Total Stack Cinders, Pounds.—A portion of the stack cinders was collected by means of a spark-trap the nozzle of which extended over the stack. The position of this nozzle, which was determined by a graduated quadrant, permitted collecting sparks from four representative portions of the outflowing stream. The weighed portions so collected were used as a basis for the determination of the total sparks emitted. Fig. 56, page 64, shows the arrangement of the spark-trap as attached to the stack.

Column 25. Moisture and Ash Free Coal Fired, Pounds, = column 17 × (1 − ((column 80 + column 83) ÷100)).

Column 26. Moisture and Ash Free Coal Fired per Hour, Pounds, = column 25 ÷ column 3.

Column 27. Moisture and Ash Free Coal Consumed, Pounds, = column 25 − (column 23 × column 100 ÷ 100) − (column 24 × column 99 ÷ 100).

Column 28. Moisture and Ash Free Coal Consumed per Hour, Pounds, = column 27 ÷ column 3.

Column 29. Per Cent of Ash in Terms of Moisture Free Coal, = (column 23 ÷ column 20) × 100.

Column 30. Per Cent of Stack Cinders in Terms of Moisture Free Coal, = (column 24 ÷ column 20) × 100.

Column 31. Steam Used by Oil Burner, Pounds.—The amount of steam used by the oil burner was determined by passing it through a calibrated orifice placed in the line leading to the burner. The drop in pressure at the orifice was determined by means of suitable pressure gages.

Column 32. Steam Pressure, Atomizer of Oil Burner, Gage, Pounds per Square Inch.—The average of observations taken at 10-minute intervals.

Tables 11 and 12, Tests Series A, and Table 23, Tests Series B Boiler Performance

134. Column 33. Temperature of Feed-Water, Firebox, Degrees Fahr.

Column 34. Temperature of Feed-Water, Barrel, Degrees Fahr.

Column 35. Temperature of Feed-Water, Degrees Fahr. All recorded feed-water temperatures are averages of observations taken at 10-minute intervals.

Column 36. Water Fed to Boiler, Corrected, Pounds.

Column 37. Water Fed to Boiler, Corrected, Firebox, Pounds.

Column 38. Water Fed to Boiler, Corrected, Barrel, Pounds.

Column 39. Water Fed to Boiler, Corrected, Total, Pounds.—The water fed to the boiler was measured in calibrated tanks provided with overflows to insure uniformity in filling. Four measuring tanks, two for each boiler, were used, each of which was supplied with a feed-water tank from which the injectors drew their supply. The arrangement of tanks is shown in Fig. 50, page 60. Each injector, of which there were four, had a separate measuring and feed-water tank. Observations were taken upon the heights of water in the feed-water tanks every twenty minutes, making possible the determination of the amount of water fed to the boiler for this interval. The overflow from each injector was received in a barrel and returned to its feed-water tank. During the tests of Series A with the partitioned boiler, one injector with its measuring and feed tanks supplied the firebox end of the boiler with water while another injector with its complement of tanks supplied the barrel end. The values given in columns 36, 37, and 38 have been corrected for leaks, which in the majority of tests amounted to nothing and in the other tests were very small and for differences of water-level and steam pressure in the boiler at the beginning and end of the tests. All tests were so conducted as to make such differences and therefore the corresponding corrections as small as possible.

Column 40. Water Fed to Boiler, Adjusted to Include Back Tube-Sheet as Part of Firebox, Firebox, Pounds.

Column 41. Water Fed to Boiler, Adjusted to Include Back Tube-Sheet as Part of Firebox, Barrel, Pounds.

Column 42. Water Fed to Boiler, Adjusted to Include Back Tube-Sheet as Part of Firebox, Total, Pounds.—Upon page 42, paragraph 42, will be found information relative to the heating-surface for firebox, barrel, and total for each of the two boilers. Where the term heating-surface appears in the following expressions it is expressed in square feet. The partitioned boiler as actually tested was so arranged that the heating-surface of the back tube-sheet was necessarily included as a part of the heating-surface of the barrel instead of as a part of the firebox heating-surface. In order that all results relative to evaporative performance which are affected by the division of the boiler into firebox end and barrel

end may be based upon the firebox heating-surface which includes the back tube-sheet and upon the barrel heating-surface which does not include the back tube-sheet the following assumption has been made: The equivalent evaporation per square foot of heating-surface of the back tube-sheet was equal to the equivalent evaporation per square foot of heating-surface of the remaining part of the firebox. In accordance with this assumption, column 40 = column 37 + (column 37 × heating-surface of back tube-sheet ÷ (heating-surface of firebox – heating-surface of back tube-sheet)), column 41 = column 38 – (column 37 × (heating-surface of back tube-sheet ÷ (heating-surface of firebox – heating-surface of back tube-sheet)) × (column 47 ÷ column 48)), and column 42 = column 40 + column 41. It will be evident that the differences which exist between corresponding values in columns 39 and 42 are due to the slightly different conditions which existed for the firebox end and barrel end as to feed-water temperature and quality of steam. All tabulated results relating to evaporative performance may be calculated either from columns 37, 38, and 39, taking into account the assumption made above, or may be calculated somewhat more readily from columns 40, 41, and 42.

Column 43. Quality of Steam, Firebox.

Column 44. Quality of Steam, Barrel.

Column 45. Quality of Steam. The quality of steam was, in all cases, determined through the use of throttling calorimeters and the results are averages of observations taken at 10-minute intervals.

Column 46. Factor of Evaporation.

Column 47. Factor of Evaporation, Firebox.

Column 48. Factor of Evaporation, Barrel.—The factor of evaporation for a given test is the ratio of the heat supplied in producing a pound of steam from average feed-water temperature to average boiler pressure under average conditions of quality to the heat of vaporization of water at 212 degrees Fahr. Expressed algebraically this becomes,

$$\frac{q + xr - h}{970.4}$$

where q = heat of liquid for average test conditions.

x = average quality of steam.

r = latent heat of vaporization for average test conditions.

h = average heat in feed-water above 32 degrees Fahr.

970.4 = latent heat of vaporization of water at 212 degrees Fahr. and 14.7 pounds pressure per square inch.

Column 49. Equivalent Evaporation, Firebox, Pounds, = column 47 × Column 40.

Column 50. Equivalent Evaporation, Barrel, Pounds = column 48 × column 41.

Column 51. Equivalent Evaporation, Total Pounds.—In Table 12 Series A this column = column 49 + column 50. In Table 23 Series B this column = column 36 × column 46.

Column 52. Equivalent Evaporation per Hour, Firebox, Pounds, = column 49 ÷ column 3.

Column 53. Equivalent Evaporation per Hour, Barrel, Pounds, = column 50 ÷ column 3.

Column 54. Equivalent Evaporation per Hour, Total, Pounds, = column 51 ÷ column 3.

Column 55. Equivalent Evaporation by Firebox, Per Cent of Total, = (column 49 ÷ column 51) × 100.

Column 56. Equivalent Evaporation per Square Foot of Heating-Surface per Hour, Firebox, Pounds.—The values in column 56 were calculated in accordance with the expression ((column 37 × column 47) ÷ column 3) ÷ ((heating-surface of firebox – heating-surface of back tube-sheet). These values are also equal to (column 52 ÷ heating-surface of firebox).

Column 57. Equivalent Evaporation per Square Foot of Heating-Surface per Hour, Barrel, Pounds, = column 53 ÷ heating-surface in the barrel.

Column 58. Equivalent Evaporation per Square Foot of Heating-Surface, per Hour, total Pounds = column 54 ÷ total heating-surface. For Series A these values are also equal to ((column 37 × column 47) + (column 38 × column 48)) ÷ (column 3 × total heating-surface).

Table 13, Tests Series A, and Table 24, Tests Series B

Boiler Performance (Continued)

135. Column 59. Boiler Horse-power Developed = column 54 ÷ 34.5.

Column 60. Ratio of Heating-Surface to Boiler Horse-power Developed, Firebox, = firebox heating-surface ÷ (column 52 ÷ 34.5).

Column 61. Ratio of Heating-Surface to Boiler Horse-power Developed, Barrel, = barrel heating-surface ÷ (column 53 ÷ 34.5).

Column 62. Ratio of Heating-Surface to Boiler Horse-power Developed = total heating-surface ÷ column 59.

Column 63. Equivalent Evaporation per Pound of Fuel as Fired, Pounds, = column 51 ÷ column 14, for all tests reported in Table 13 in which oil was used as fuel, and = column 51 ÷ column 17, for all tests in which coal was used as fuel.

Column 64. Equivalent Evaporation per Pound of Moisture Free Coal Fired, Pounds, = column 51 ÷ column 20.

Column 65. Equivalent Evaporation per Pound of Moisture and Ash Free Coal Consumed, Pounds, = column 51 ÷ column 27.

Column 66. B.t.u. Absorbed by Boiler per Pound of Oil = column 63 × 970.4.

Column 67. B.t.u. Absorbed by the Boiler per Pound of Moisture Free Coal Fired = column 64 × 970.4.

Column 68. B.t.u. Absorbed by the Boiler per Pound of Moisture Free Coal Consumed = (column 70 $\times$ column 103) $\div$ 100.

Column 69. Overall Efficiency, per cent.—This is the ratio of the heat units absorbed by the boiler to the heat units fired,

= column 66 $\div$ column 101 for all tests reported in Table 13 in which oil was used as fuel,

= column 67 $\div$ column 103 for all tests in which coal was used as fuel.

Column 70. Efficiency of Boiler and Furnace Excluding Grate, per cent.—This is the ratio of the heat units absorbed by the boiler to the heat units which may be considered as rising from the grate, = (column 65 $\times$ 970.4) $\div$ column 104.

Table 14, Tests Series A, and Table 25, Tests Series B
Smoke-box Gases and Air Supply

136. Column 71. Gas Analysis, CO_2, per cent. by volume.

Column 72. Gas Analysis, O_2, per cent. by volume.

Column 73. Gas Analysis, CO, per cent. by volume. The gas analyses were made with the Orsat apparatus and are averages for continuous samples. Fig. 52, page 61, shows the position of the gas sampling tubes. Where insufficient data regarding gas analyses or data that were obviously in error were secured these have been omitted from the tabulations.

Column 74. Gas Analysis, N, per cent. by Volume = 100 − (column 71 + column 72 + column 73).

Column 75. Dry Gas per Pound of Carbon Consumed, Pounds, = (4 $\times$ column 71 + column 72 + 700) $\div$ (3 $\times$ (column 71 + column 73)).

Column 76. Dry Gas per Pound of Moisture Free Coal Fired, Pounds, = (column 75 $\times$ column 85).

Column 77. Air per Pound of Carbon Consumed, Pounds, = column 74 $\div$ (.33 $\times$ (column 71 + column 73)).

Column 78. Air per Pound of Moisture Free Coal Fired, Pounds, = column 85 $\times$ column 77.

Column 79. Ratio of Air Supplied to Theoretical Requirement = column 74 $\div$ (column 74 − (3.77 $\times$ column 72)).

Table 15, Tests Series A, and Table 26, Tests Series B
Chemical Analysis—Coal

137. The chemical analyses and determinations of calorific values for oil, coal, ash and stack cinders were made at the Pittsburgh laboratory of the United States Bureau of Mines. For the tests during which oil fuel was used one composite sample made up from separate samples for each test was analyzed and reported upon. For the tests during which coal was

burned one sample each of coal, ash, and stack cinders were submitted for each test, proximate analysis being made for each sample submitted and calorific determinations being made for all coal and stack cinder samples. Ultimate analyses were made for one sample of Scalp-Level coal and for one sample of Dundon coal. From the ultimate analyses submitted by the chemist an ultimate analysis was calculated for the coal of each test upon the basis of its ash and sulphur as shown by the proximate analysis for that sample and upon the assumption that the hydrogen, carbon, nitrogen, and oxygen bore the same quantitative relation to each other in all samples, namely, that shown by the single ultimate analysis.

Column 80 to 89, inclusive, Chemical Analyses, obtained from the report of the chemist.

Table 16, Tests Series A, and Table 27, Tests Series B
Chemical Analyses—Stack Cinders—Ash—Oil

138. Columns 90 to 98, inclusive, Chemical Analyses, obtained from the report of the chemist.

Table 17, Tests Series A, and Table 28, Tests Series B
Calorific Values

139. Column 99. Per cent. of Combustible in Stack Cinders = column 91 + column 92.

Column 100. Per cent. of Combustible in Ash = column 95 + column 96.

Column 101 to 105, inclusive, Calorific Values by Oxygen Calorimeter, B.t.u., obtained from the report of the chemist.

Column 106. Calorific Value per Pound of Ash, Estimated, B.t.u.,—for all tests during which Scalp-Level coal was burned column 106 = column 104 $\times$ (column 100 $\div$ 100) $\times$ 0.912 and for all tests during which Dundon coal was burned column 106 = column 104 $\times$ (column 100 $\div$ 100) $\times$ 0.945. The constants 0.912 and 0.945 appearing in these expressions were determined in the following manner. Upon examination of the calorific values submitted by the chemist for stack cinders it was found that the combustible contained in those cinders had a heating value uniformly lower than the combustible in the coal from which the cinders originated. In the case of the Scalp-Level coal tests the average calorific value of the combustible in the stack cinders was found to be 91.2 per cent. of the combustible in the coal. In the case of the Dundon coal tests the corresponding figure was found to be 94.5 per cent. These figures were employed in the above expression for computing the calorific value of the ash, thus assuming that the combustible in the ash was of substantially the same calorific value as the combustible in the stack cinders.

Table 18, Tests Series A, and Table 29, Tests Series B
Heat Balance—British Thermal Units

140. Where insufficient data have been secured or data relative to gas analyses have been omitted the corresponding heat balances have also been omitted. The reliability of data relative to flue-gas analyses is not comparable with that of other portions of the data. Heat balances for all tests during which coal was burned for which sufficient data were secured are presented notwithstanding the fact that some of the results are obviously inconsistent.

Column 107. B.t.u. per Pound of Moisture Free Coal = column 103.

Column 108. B.t.u. absorbed by Boiler per Pound of Moisture Free Coal = column 67.

Column 109. Loss Due to Moisture in Coal, B.t.u., = (column 80 $\div$ (100 $-$ column 80)) $\times$ ((212 $-$ column 8) + 970.4 + 0.47 $\times$ (column 11 $-$ 212)).

Column 110. Loss Due to Moisture in Air, B.t.u., = ((grains moisture per pound of air) $\div$ 7,000) $\times$ column 78 $\times$ (0.47 $\times$ (column 11 $-$ column 8)). The number of grains of moisture per pound of air was determined by means of psychometric tables and the data given in columns 8 and 9.

Column 111. Loss Due to Hydrogen in Coal, B.t.u., = (column 84 $\div$ 100) $\times$ 9 $\times$ ((212 $-$ column 8) + 970.4 + (0.47 $\times$ (column 11 $-$ 212)).

Column 112. Loss Due to Escaping Gases, B.t.u., = 0.24 $\times$ column 76 $\times$ (column 11 $-$ column 8).

Column 113. Loss Due to Incomplete Combustion, B.t.u., = (column 85 $\div$ 100) $\times$ (column 73 $\div$ (column 71 + column 73)) $\times$ 10,150.

Column 114. Loss Due to Stack Cinders, B.t.u., = (column 24 $\div$ column 20) $\times$ column 105.

Column 115. Loss Due to Ash, B.t.u., = (column 23 $\div$ column 20) $\times$ column 106.

Column 116. Loss Due to Radiation and Unaccounted for, B.t.u., = column 107 $-$ (column 108 + column 109 + column 110 + column 111 + column 112 + column 113 + column 114 + column 115).

Table 19, Tests Series A, and Table 30, Tests Series B
Heat Balance—Percentages

141. Column 117. Heat Absorbed by the Boiler, per cent., = (column 108 $\div$ column 107) $\times$ 100.

Column 118. Heat Loss Due to Moisture in Coal, per cent., = (column 109 $\div$ column 107) $\times$ 100.

Column 119. Heat Loss Due to Moisture in Air, per cent., = (column 110 $\div$ column 107) $\times$ 100.

Column 120. Heat Loss Due to Hydrogen in Coal, per cent., = (column 111 ÷ column 107) × 100.

Column 121. Heat Loss Due to Escaping Gases, per cent., = (column 112 ÷ column 107) × 100.

Column 122. Heat Loss Due to Incomplete Combustion, per cent., = (column 113 ÷ column 107) × 100.

Column 123. Heat Loss Due to Combustible in Stack Cinders, per cent., = (column 114 ÷ column 107) × 100.

Column 124. Heat Loss Due to Combustible in Ash, per cent., = (column 115 ÷ column 107) × 100.

Column 125. Heat Loss Due to Radiation and Unaccounted for, per cent., = (column 116 ÷ column 107) × 100.

GENERAL CONDITIONS

TESTS SERIES A

Table 8

DESIGNATION OF TEST	DATE OF TEST	DURATION OF TEST hours	POWER	BAROMETRIC PRESSURE lbs. per sq. in.	BOILER PRESSURE lbs. per sq. in.	TEMPERATURE—DEGREES FAHRENHEIT				DRAFT	
						LABORATORY					
						BY DRY BULB THERMOMETER	BY WET BULB THERMOMETER	OUTSIDE AIR	SMOKE BOX GASES	BACK OF DIAPHRAGM ins. of water	FRONT OF DIAPHRAGM ins. of water
1	2	3	4	6	7	8	9	10	11	12	13
A- 1-J	3-18-12	5.00	Low	14.6	216.4	72.0	70.9	68	455	1.2	1.5
A- 2-J	3-12-12	3.67	Medium	14.5	210.4	53.6	....	37	566	1.9	2.6
A- 3-J	3-20-12	4.00	Medium	14.6	215.2	57.9	56.6	61	562	2.0	3.0
A- 4-J	3-11-12	3.00	High	14.5	212.2	50.0	49.4	37	730	3.2	5.2
A- 5-J	3-20-12	3.00	High	14.6	215.0	59.0	58.8	60	642	4.0	6.5
A- 6-R	3-13-12	5.00	Low	14.4	216.4	57.8	57.2	49	473	0.9	1.2
A- 7-R	3-12-12	3.00	Medium	14.5	211.7	49.5	....	36	598	2.0	2.8
A- 8-R	3-16-12	4.00	Medium	15.1	217.6	54.9	....	44	582	2.0	2.6
A- 9-R	3- 8-12	3.00	High	14.3	214.8	53.0	52.3	41	674	4.0	6.1
A-101-J	3-29-12	6.00	Low	14.3	217.6	68.6	....	67	529	0.6	1.2
A-102-J	4- 3-12	5.00	Low	14.5	215.1	47.0	46.0	49	562	0.8	1.3
A-103-J	3-30-12	3.83	Medium	14.7	217.0	49.9	47.9	50	609	2.2	4.4
A-104-J	4- 3-12	3.00	Medium	14.5	214.1	42.6	....	44	581	2.1	4.2
A-105-J	4- 1-12	2.00	High	14.6	215.2	64.0	....	59	617	3.2	7.3
A-106-J	4- 5-12	2.00	High	14.7	214.0	56.1	49.4	55	639	3.3	6.7
A-107-R	4- 4-12	5.00	Low	14.8	216.8	51.3	45.3	46	602	0.9	1.5
A-108-R	3-28-12	7.00	Low	14.6	217.0	61.5	61.2	59	499	0.6	1.1
A-109-R	3-27-12	4.00	Medium	14.6	215.6	56.9	55.8	57	572	1.9	3.4
A-110-R	4- 2-12	3.33	Medium	14.2	216.5	65.6	....	62	568	1.6	3.1
A-111-R	4- 1-12	2.00	High	14.6	214.7	54.2	54.2	50	618	3.9	7.7
A-112-R	4- 4-12	2.00	High	14.8	214.2	56.1	48.9	51	615	3.2	6.4

FUEL

TESTS SERIES A

Table 9

DESIGNATION OF TEST	OIL		KIND OF COAL	COAL AS FIRED			MOISTURE FREE COAL		
	TOTAL pounds	PER HOUR pounds		TOTAL pounds	PER HOUR pounds	PER SQ.FT. OF GRATE PER HOUR pounds	TOTAL pounds	PER HOUR pounds	PER SQ.FT. OF GRATE PER HOUR pounds
1	14	15	16	17	18	19	20	21	22
A- 1-J	3,678	736	......	.....	.....	.....	.....	.....	.....
A- 2-J	5,327	1,453	......	.....	.....	.....	.....	.....	.....
A- 3-J	5,596	1,399	......	.....	.....	.....	.....	.....	.....
A- 4-J	6,467	2,156	......	.....	.....	.....	.....	.....	.....
A- 5-J	6,351	2,117	......	.....	.....	.....	.....	.....	.....
A- 6-R	3,951	790	......	.....	.....	.....	.....	.....	.....
A- 7-R	4,513	1,504	......	.....	.....	.....	.....	.....	.....
A- 8-R	5,758	1,440	......	.....	.....	.....	.....	.....	.....
A- 9-R	6,319	2,106	......	.....	.....	.....	.....	.....	.....
A-101-J	.....	.....	Scalp Level	8,206	1,368	24.1	7,946	1,324	23.3
A-102-J	.....	.....	Dundon	8,285	1,657	29.2	8,109	1,622	28.6
A-103-J	.....	.....	Scalp Level	9,871	2,575	45.3	9,577	2,498	44.0
A-104-J	.....	.....	Dundon	9,269	3,090	54.4	8,969	2,990	52.6
A-105-J	.....	.....	Dundon	8,682	4,341	76.4	8,455	4,228	74.4
A-106-J	.....	.....	Dundon	8,929	4,465	78.6	8,783	4,392	77.3
A-107-R	.....	.....	Dundon	8,784	1,757	30.2	8,606	1,721	29.6
A-108-R	.....	.....	Scalp Level	10,165	1,452	25.0	10,040	1,434	24.7
A-109-R	.....	.....	Scalp Level	9,888	2,472	42.5	9,672	2,418	41.6
A-110-R	.....	.....	Dundon	9,677	2,903	49.9	9,449	2,835	48.7
A-111-R	.....	.....	Dundon	8,690	4,345	74.7	8,500	4,250	73.1
A-112-R	.....	.....	Dundon	8,542	4,271	73.4	8,275	4,138	71.1

FUEL (Continued)

TESTS SERIES A

Table 10

DESIGNATION OF TEST	ASH TOTAL pounds	STACK CINDERS TOTAL pounds	MOISTURE AND ASH FREE COAL FIRED		MOISTURE AND ASH FREE COAL CONSUMED		PER CENT. OF ASH IN TERMS OF MOISTURE FREE COAL	PER CENT. OF STACK CINDERS IN TERMS OF MOISTURE FREE COAL	STEAM USED BY OIL BURNER pounds	STEAM PRESSURE AT ATOMIZER OF OIL BURNER lbs. per sq. in.
			TOTAL pounds	PER HOUR pounds	TOTAL pounds	PER HOUR pounds				
1	23	24	25	26	27	28	29	30	31	32
A- 1-J	....	....	....	....	....	....	....	....	420	9.5
A- 2-J	....	....	....	....	....	....	....	....	262	7.6
A- 3-J	....	....	....	....	....	....	....	....	285	7.6
A- 4-J	....	....	....	....	....	....	....	....	193	6.2
A- 5-J	....	....	....	....	....	....	....	....	250	9.4
A- 6-R	....	....	....	....	....	....	....	....	351	7.3
A- 7-R	....	....	....	....	....	....	....	....	232	8.5
A- 8-R	....	....	....	....	....	....	....	....	305	8.2
A- 9-R	....	....	....	....	....	....	....	....	158	4.2
A-101-J	353	112	7,511	1,252	7,197	1,200	4.4	1.4	....	....
A-102-J	230	68	7,365	1,473	7,279	1,456	2.8	0.8	....	....
A-103-J	365	492	9,109	2,376	8,456	2,206	3.8	5.1	....	....
A-104-J	270	70	7,434	2,478	7,336	2,445	3.0	0.8	....	....
A-105-J	65	93	7,753	3,877	7,670	3,835	0.8	1.1	....	....
A-106-J	218	93	8,015	4,008	7,900	3,950	2.5	1.1	....	....
A-107-R	315	87	7,870	1,574	7,774	1,555	3.7	1.0	....	....
A-108-R	353	208	9,436	1,348	9,078	1,297	3.5	2.1	....	....
A-109-R	292	479	9,211	2,303	8,675	2,169	3.0	5.0	....	....
A-110-R	256	76	8,648	2,594	8,568	2,570	2.7	0.8	....	....
A-111-R	229	61	7,557	3,779	7,465	3,733	2.7	0.7	....	....
A-112-R	404	61	7,376	3,688	7,248	3,624	4.9	0.7	....	....

BOILER PERFORMANCE

TESTS SERIES A

Table 11

DESIGNATION OF TEST	TEMPERATURE OF FEED WATER		WATER FED TO BOILER CORRECTED			WATER FED TO BOILER ADJUSTED TO INCLUDE BACK TUBE SHEET AS PART OF FIREBOX			QUALITY OF STEAM		FACTOR OF EVAPORATION	
	FIRE-BOX degr. fahr.	BAR-REL degr. fahr.	FIRE-BOX lbs.	BAR-REL lbs.	TOTAL lbs.	FIRE-BOX lbs.	BAR-REL lbs.	TOTAL lbs.	FIRE-BOX	BAR-REL	FIRE-BOX	BAR-REL
1	33	34	37	38	39	40	41	42	43	44	47	48
A- 1-J	53.8	53.5	22,145	26,376	48,521	25,315	23,195	48,510	0.998	0.993	1.2119	1.2079
A- 2-J	45.3	45.0	27,440	38,801	66,241	31,368	34,847	66,215	0.997	0.986	1.2191	1.2111
A- 3-J	55.7	55.3	26,733	42,468	69,201	30,559	38,635	69,194	0.995	0.992	1.2078	1.2061
A- 4-J	43.7	43.1	25,083	48,951	74,034	28,674	45,307	73,981	0.997	0.976	1.2223	1.2042
A- 5-J	55.7	54.4	24,315	47,676	71,991	27,796	44,182	71,978	0.997	0.991	1.2095	1.2052
A- 6-R	46.7	44.9	24,570	26,523	51,093	28,340	22,750	51,090	0.997	0.994	1.2198	1.2190
A- 7-R	46.8	44.9	20,804	33,086	53,890	23,997	29,896	53,893	0.996	0.995	1.2181	1.2184
A- 8-R	49.5	46.8	31,181	40,043	71,224	35,966	35,258	71,224	0.997	0.995	1.2173	1.2178
A- 9-R	47.6	44.5	25,502	43,001	68,503	29,415	39,082	68,497	0.996	0.991	1.2179	1.2164
A-101-J	56.7	56.6	26,705	45,547	72,252	30,527	41,708	72,235	0.996	0.990	1.2087	1.2034
A-102-J	54.2	54.5	25,088	33,864	58,952	28,678	30,263	58,941	0.996	0.992	1.2106	1.2071
A-103-J	52.9	52.4	24,727	55,388	80,115	28,266	51,842	80,108	0.997	0.993	1.2134	1.2110
A-104-J	55.0	53.4	21,319	42,392	63,711	24,371	39,339	63,710	0.996	0.993	1.2096	1.2089
A-105-J	56.5	57.0	17,371	41,369	58,740	19,857	38,878	58,735	0.994	0.993	1.2068	1.2050
A-106-J	50.8	51.6	17,387	39,333	56,720	19,875	36,846	56,721	0.994	0.995	1.2118	1.2126
A-107-R	52.4	50.3	25,810	35,039	60,849	29,771	31,077	60,848	0.997	0.994	1.2134	1.2129
A-108-R	56.5	54.4	32,029	54,833	86,862	36,945	49,916	86,861	0.997	0.994	1.2095	1.2088
A-109-R	53.9	52.3	22,123	57,709	79,832	25,519	54,307	79,826	0.998	0.993	1.2123	1.2099
A-110-R	59.0	57.0	23,604	43,979	67,583	27,226	40,355	67,581	0.996	0.993	1.2056	1.2049
A-111-R	56.4	56.3	17,204	42,116	59,320	19,845	39,468	59,313	0.996	0.992	1.2086	1.2051
A-112-R	55.4	52.9	15,780	41,314	57,094	18,202	38,895	57,097	0.996	0.995	1.2096	1.2106

BOILER PERFORMANCE (Continued)

TESTS SERIES A

Table 12

DESIGNATION OF TEST	EQUIVALENT EVAPORATION			EQUIVALENT EVAPORATION PER HOUR			EQUIVALENT EVAPORATION BY FIREBOX PER CENT. OF TOTAL	EQUIVALENT EVAPORATION PER SQ. FT. OF HEATING SURFACE PER HOUR		
	FIRE-BOX pounds	BARREL pounds	TOTAL pounds	FIRE-BOX pounds	BARREL pounds	TOTAL pounds		FIRE-BOX pounds	BARREL pounds	TOTAL pounds
1	49	50	51	52	53	54	55	56	57	58
A– 1–J	30,680	28,018	58,698	6,136	5,604	11,740	52.27	26.59	2.02	3.90
A– 2–J	38,240	42,205	80,445	10,428	11,509	21,937	47.54	45.18	4.14	7.29
A– 3–J	36,908	46,598	83,506	9,227	11,650	20,877	44.27	39.98	4.19	6.94
A– 4–J	35,048	54,558	89,606	11,683	18,186	29,869	39.11	50.62	6.55	9.93
A– 5–J	33,619	53,249	86,868	11,206	17,750	28,956	38.70	48.55	6.39	9.63
A– 6–R	34,569	27,732	62,301	6,914	5,546	12,460	55.48	33.45	2.00	4.18
A– 7–R	29,230	36,423	65,653	9,743	12,141	21,884	44.52	47.14	4.37	7.33
A– 8–R	43,782	42,935	86,717	10,946	10,734	21,680	50.49	52.96	3.86	7.27
A– 9–R	35,825	47,540	83,365	11,942	15,847	27,789	42.97	57.78	5.71	9.31
A–101–J	36,896	50,191	87,087	6,149	8,363	14,514	42.36	26.64	3.01	4.82
A–102–J	34,718	36,530	71,248	6,944	7,306	14,250	48.74	30.09	2.63	4.74
A–103–J	34,300	62,781	97,081	8,949	16,379	25,328	35.33	38.77	5.90	8.42
A–104–J	29,479	47,558	77,037	9,826	15,853	25,679	38.27	42.57	5.71	8.54
A–105–J	23,964	46,846	70,810	11,982	23,423	35,405	33.84	51.92	8.43	11.77
A–106–J	24,085	44,680	68,765	12,043	22,340	34,383	35.03	52.18	8.04	11.43
A–107–R	36,125	37,692	73,817	7,225	7,538	14,763	48.93	34.95	2.71	4.95
A–108–R	44,683	60,337	105,020	6,383	8,620	15,003	42.54	30.88	3.10	5.03
A–109–R	30,936	65,707	96,643	7,734	16,427	24,161	32.01	37.42	5.91	8.10
A–110–R	32,824	48,625	81,449	9,848	14,589	24,437	40.30	47.64	5.25	8.19
A–111–R	23,984	47,563	71,547	11,992	23,782	35,774	33.52	58.02	8.56	11.99
A–112–R	22,017	47,087	69,104	11,009	23,544	34,553	31.86	53.26	8.48	11.58

BOILER PERFORMANCE (Continued)

TESTS SERIES A

Table 13

DESIGNATION OF TEST	BOILER HORSE POWER DEVELOPED	RATIO OF HEATING SURFACE TO BOILER HORSE-POWER DEVELOPED			EQUIVALENT EVAPORATION			B. T. U. ABSORBED BY THE BOILER			EFFICIENCY	
		FIRE-BOX	BAR-REL	TOTAL	PER POUND OF FUEL AS FIRED lbs.	PER POUND OF MOIS-TURE FREE COAL FIRED lbs.	PER POUND OF MOIS-TURE AND ASH FREE COAL CON-SUMED lbs.	PER POUND OF OIL	PER POUND OF MOIS-TURE FREE COAL FIRED	PER POUND OF MOIS-TURE FREE COAL CON-SUMED	[OVER ALL] PER CENT. OF B.T.U. ABSORBED BY THE BOILER PER POUND OF FUEL FIRED	[BOILER AND FURNACE EXCLUDING GRATE] PER CENT. OF B.T.U. ABSORBED BY THE BOILER PER POUND OF FUEL CON-SUMED
1	59	60	61	62	63	64	65	66	67	68	69	70
A- 1-J	340	1.30	17.10	8.84	15.96	......	......	15,488	......	......	80.68	.....
A- 2-J	636	0.76	8.33	4.73	15.10	......	......	14,655	......	......	76.35	.....
A- 3-J	605	0.87	8.23	4.97	14.92	......	......	14,481	......	......	75.44	.....
A- 4-J	866	0.68	5.27	3.48	13.86	......	......	13,446	......	......	70.05	.....
A- 5-J	839	0.71	5.40	3.58	13.68	......	......	13,273	......	......	69.15	.....
A- 6-R	361	1.03	17.27	8.26	15.77	......	......	15,302	......	......	79.72	.....
A- 7-R	634	0.73	7.89	4.70	14.55	......	......	14,118	......	......	73.55	.....
A- 8-R	628	0.65	8.93	4.75	15.06	......	......	14,615	......	......	76.14	.....
A- 9-R	806	0.60	6.05	3.71	13.20	......	......	12,809	......	......	66.70	.....
A-101-J	421	1.33	11.45	7.39	10.61	10.96	12.10	......	10,636	11,101	71.62	74.75
A-102-J	413	1.15	13.12	7.28	8.60	8.79	9.79	......	8,526	8,626	62.01	62.74
A-103-J	734	0.89	5.85	4.15	9.84	10.14	11.48	......	9,837	10,595	65.79	70.86
A-104-J	744	0.81	6.04	4.04	8.31	8.59	10.50	......	8,335	8,447	67.39	68.30
A-105-J	1,026	0.66	4.08	2.93	8.16	8.38	9.23	......	8,127	8,215	58.65	59.28
A-106-J	997	0.66	4.30	3.02	7.70	7.83	8.70	......	7,597	7,707	55.12	55.91
A-107-R	428	0.99	12.70	6.96	8.40	8.58	9.50	......	8,323	8,428	60.22	60.97
A-108-R	435	1.12	11.11	6.86	10.33	10.46	11.57	......	10,150	10,549	68.65	71.35
A-109-R	700	0.92	5.83	4.26	9.77	9.99	11.14	......	9,696	10,295	64.68	68.68
A-110-R	708	0.72	6.57	4.21	8.42	8.62	9.51	......	8,365	8,442	60.51	61.07
A-111-R	1,037	0.59	4.03	2.88	8.23	8.42	9.58	......	8,168	8,270	61.10	61.86
A-112-R	1,002	0.65	4.07	2.98	8.19	8.35	9.54	......	8,104	8,249	60.09	61.16

SMOKE BOX GASES AND AIR SUPPLY

TESTS SERIES A

Table 14

DESIGNATION OF TEST	GAS ANALYSIS PER CENT BY VOLUME				DRY GAS PER POUND		AIR PER POUND		RATIO OF AIR SUPPLIED TO THEORETICAL REQUIREMENT
	CO_2	O_2	CO	N	CARBON CONSUMED pounds	MOISTURE FREE COAL FIRED pounds	CARBON CONSUMED pounds	MOISTURE FREE COAL FIRED pounds	
1	71	72	73	74	75	76	77	78	79
A- 1-J	13.1	3.1	0.0	83.8	19.2	.....	19.4	.....	1.2
A- 2-J	13.0	1.2	0.2	85.6	19.0	.....	19.6	.....	1.1
A- 3-J	12.1	3.5	0.0	84.4	20.7	.....	21.2	.....	1.2
A- 4-J	12.4	2.6	0.3	84.7	19.7	.....	20.2	.....	1.1
A- 5-J	13.7	0.4	0.7	85.2	17.5	.....	17.9	.....	1.0
A- 6-R	11.4	5.3	0.0	83.3	22.0	.....	22.2	.....	1.3
A- 7-R	10.4	5.9	0.0	83.7	24.0	.....	24.4	.....	1.4
A- 8-R	12.9	2.8	0.0	84.3	19.5	.....	19.8	.....	1.1
A- 9-R	12.4	2.3	0.2	85.1	19.9	.....	20.5	.....	1.1
A-101-J	10.1	8.0	0.4	81.5	23.8	20.4	23.5	20.2	1.6
A-102-J	9.2	7.5	0.5	82.8	25.6	19.7	25.9	20.0	1.5
A-103-J	7.0	11.7	0.1	81.2	34.7	30.0	34.7	30.0	2.2
A-104-J	12.5	3.3	2.7	81.5	16.5	11.6	16.2	11.4	1.2
A-105-J	12.9	2.8	2.8	81.5	16.0	12.5	15.7	12.3	1.2
A-106-J	11.7	3.2	2.0	83.1	18.3	14.2	18.4	14.3	1.2
A-107-R	7.4	11.6	0.3	80.7	32.1	24.9	31.8	24.7	2.2
A-108-R	9.7	8.5	0.1	81.7	25.4	21.7	25.3	21.6	1.7
A-109-R	11.9	5.3	0.2	82.6	20.7	18.0	20.7	17.9	1.3
A-110-R	8.7	9.8	0.3	81.2	27.6	21.5	27.3	21.3	1.8
A-111-R	8.0	10.8	0.4	80.8	29.5	22.3	29.2	22.1	2.0
A-112-R	9.7	8.8	0.3	81.2	24.9	18.9	24.6	18.7	1.7

CHEMICAL ANALYSIS—COAL

TESTS SERIES A

Table 15

DESIGNATION OF TEST	Proximate Analysis Coal as Fired				Ultimate Analysis Moisture Free Coal					
	MOISTURE per cent.	VOLATILE MATTER per cent.	FIXED CARBON per cent.	ASH per cent.	HYDROGEN per cent.	CARBON per cent.	NITROGEN per cent.	OXYGEN per cent.	SULPHUR per cent.	ASH per cent.
1	80	81	82	83	84	85	86	87	88	89
A- 1-J	....	....	....	....	....	....	....	....	....	....
A- 2-J	....	....	....	....	....	....	....	....	....	....
A- 3-J	....	....	....	....	....	....	....	....	....	....
A- 4-J	....	....	....	....	....	....	....	....	....	....
A- 5-J	....	....	....	....	....	....	....	....	....	....
A- 6-R	....	....	....	....	....	....	....	....	....	....
A- 7-R	....	....	....	....	....	....	....	....	....	....
A- 8-R	....	....	....	....	....	....	....	....	....	....
A- 9-R	....	....	....	....	....	....	....	....	....	....
A-101-J	3.17	16.14	75.40	5.30	4.34	85.86	1.33	2.30	0.69	5.47
A-102-J	2.12	36.52	52.39	8.98	4.81	77.18	1.52	6.40	0.92	9.17
A-103-J	2.98	16.40	75.86	4.75	4.37	86.46	1.34	2.31	0.62	4.90
A-104-J	3.24	31.58	48.62	16.56	4.39	70.43	1.39	5.84	0.84	17.11
A-105-J	2.62	34.72	54.58	8.08	4.86	77.92	1.53	6.46	0.93	8.30
A-106-J	1.63	35.42	54.35	8.60	4.83	77.54	1.53	6.43	0.93	8.74
A-107-R	2.03	35.61	53.98	8.38	4.85	77.73	1.53	6.45	0.90	8.55
A-108-R	1.23	16.36	76.47	5.94	4.31	85.43	1.33	2.29	0.63	6.01
A-109-R	2.18	17.05	76.10	4.66	4.37	86.59	1.34	2.32	0.62	4.76
A-110-R	2.36	34.82	54.55	8.28	4.85	77.86	1.53	6.46	0.82	8.48
A-111-R	2.19	34.56	52.40	10.84	4.71	75.59	1.49	6.27	0.86	11.08
A-112-R	3.13	33.74	52.62	10.52	4.73	75.87	1.49	6.29	0.75	10.86

CHEMICAL ANALYSIS—STACK CINDERS—ASH—OIL

TESTS SERIES A

Table 16

DESIGNATION OF TEST	PROXIMATE ANALYSIS STACK CINDERS				PROXIMATE ANALYSIS ASH				ULTIMATE ANALYSIS OF OIL
	MOISTURE per cent.	VOLATILE MATTER per cent.	FIXED CARBON per cent.	ASH per cent.	MOISTURE per cent.	VOLATILE MATTER per cent.	FIXED CARBON per cent.	ASH per cent.	
1	90	91	92	93	94	95	96	97	98
A- 1-J	.....	.....	.....	.....	.....	.....	.....	.....	
A- 2-J	.....	.....	.....	.....	.....	.....	.....	.....	*per cent.*
A- 3-J	.....	.....	.....	.....	.....	.....	.....	.....	Hydrogen..... 12.39
A- 4-J	.....	.....	.....	.....	.....	.....	.....	.....	Carbon........ 86.85
A- 5-J	.....	.....	.....	.....	.....	.....	.....	.....	Sulphur....... 0.29
A- 6-R	.....	.....	.....	.....	.....	.....	.....	.....	Water......... 0.00
A- 7-R	.....	.....	.....	.....	.....	.....	.....	.....	Sand.......... 0.00
A- 8-R	.....	.....	.....	.....	.....	.....	.....	.....	
A- 9-R	.....	.....	.....	.....	.....	.....	.....	.....	99.53
A-101-J	1.22	3.73	62.80	32.25	0.35	3.25	65.23	31.17	
A-102-J	16.45	4.96	43.56	35.03	7.89	2.73	20.34	69.04	Specific Gravity (at 15° C.)... 0.8875
A-103-J	0.42	2.43	74.33	22.82	0.21	2.32	73.42	24.05	Viscosity (Engler
A-104-J	1.08	4.76	52.42	41.74	7.80	2.27	19.21	70.72	Degree at 20° C.) 1.6
A-105-J	.....	.....	.....	.....	8.03	2.14	20.40	69.43	Flash Point—
A-106-J	0.50	2.65	71.20	25.65	6.97	1.57	19.37	72.09	(Pensky-Martens, closed
A-107-R	7.33	6.10	43.44	43.13	0.40	1.78	15.10	82.72	tube)..... 60° C.
A-108-R	8.10	3.93	66.71	28.55	0.38	4.71	55.80	39.11	Ignition Point—
A-109-R	0.37	2.74	72.53	24.36	0.32	5.09	55.14	39.45	(Pensky-Martens, closed
A-110-R	0.78	4.45	42.94	51.83	0.53	1.86	15.15	82.46	tube)..... 87° C.
A-111-R	.....	.....	.....	.....	0.32	1.48	20.56	77.64	Calories, per gram,
A-112-R	0.48	2.34	67.36	29.82	0.35	1.67	19.67	78.31	high value ... 10664

CALORIFIC VALUES

TESTS SERIES A

Table 17

DESIGNATION OF TEST	PER CENT. OF COMBUSTIBLE IN STACK CINDERS	PER CENT. OF COMBUSTIBLE IN ASH	CALORIFIC VALUE BY OXYGEN CALORIMETER					CALORIFIC VALUE PER POUND OF ASH [ESTIMATED] B.T.U.
			PER POUND OF OIL B.T.U.	PER POUND OF COAL AS FIRED B.T.U.	PER POUND OF MOISTURE FREE COAL B.T.U.	PER POUND OF MOISTURE AND ASH FREE COAL B.T.U.	PER POUND OF STACK CINDERS B.T.U.	
1	99	100	101	102	103	104	105	106
A- 1-J	....	....	19,195	.....	.....	.....	.....	.....
A- 2-J	.....	....	19,195	.....	.....	.....	.....	.....
A- 3-J	.....	....	19,195	.....	.....	.....	.....	.....
A- 4-J	.....	.....	19,195	.....	.....	.....	.....	.....
A- 5-J	.....	.....	19,195	.....	.....	.....	.....	.....
A- 6-R	.....	.....	19,195	.....	.....	.....	.....	.....
A- 7-R	.....	....	19,195	.....	.....	.....	.....	.....
A- 8-R	.....	.....	19,195	.....	.....	.....	.....	.....
A- 9-R	.....	.....	19,195	.....	.....	.....	.....	.....
A-101-J	66.53	68.48	.....	14,380	14,850	15,710	9,585	9,809
A-102-J	48.52	23.07	.....	13,458	13,750	15,140	6,766	3,299
A-103-J	76.76	75.74	.....	14,506	14,953	15,721	10,958	10,857
A-104-J	57.18	21.48	.....	11,967	12,368	14,920	8,233	3,074
A-105-J	.....	22.54	.....	13,495	13,858	15,113	.....	3,217
A-106-J	73.85	20.94	.....	13,559	13,784	15,106	10,510	2,988
A-107-R	49.54	16.88	.....	13,542	13,822	15,115	6,937	2,410
A-108-R	70.64	60.51	.....	14,604	14,785	15,734	10,193	8,612
A-109-R	75.27	60.23	.....	14,663	14,990	15,741	10,701	8,645
A-110-R	47.39	17.01	.....	13,498	13,824	15,106	6,865	2,428
A-111-R	.....	22.04	.....	13,076	13,369	15,035	.....	3,130
A-112-R	69.70	21.34	.....	13,065	13,486	15,129	9,878	3,050

HEAT BALANCE—BRITISH THERMAL UNITS

TESTS SERIES A

Table 18

DESIGNATION OF TEST	B. T. U. PER POUND OF MOISTURE FREE COAL	B. T. U. ABSORBED BY BOILER PER POUND OF MOISTURE FREE COAL	B. T. U. LOSS PER POUND OF MOISTURE FREE COAL FIRED							
			DUE TO MOISTURE IN COAL	DUE TO MOISTURE IN AIR	DUE TO HYDROGEN IN COAL	DUE TO ESCAPING GASES	DUE TO INCOMPLETE COMBUSTION	DUE TO COMBUSTIBLE IN STACK CINDERS	DUE TO COMBUSTIBLE IN ASH	DUE TO RADIATION AND UNACCOUNTED FOR
1	107	108	109	110	111	112	113	114	115	116
A- 1-J	....	....	....	....	....	....	....	....	....	....
A- 2-J	....	....	....	....	....	....	....	....	....	....
A- 3-J	....	....	....	....	....	....	....	....	....	....
A- 4-J	....	....	....	....	....	....	....	....	....	....
A- 5-J	....	....	....	....	....	....	....	....	....	....
A- 6-R	....	....	....	....	....	....	....	....	....	....
A- 7-R	....	....	....	....	....	....	....	....	....	....
A- 8-R	....	....	....	....	....	....	....	....	....	....
A- 9-R	....	....	....	....	....	....	....	....	....	....
A-101-J	14,851	10,636	41	....	493	2,252	331	133	436	528
A-102-J	13,749	8,526	28	29	563	2,440	407	57	94	1,605
A-103-J	14,952	9,837	41	55	519	4,029	123	562	414	-628
A-104-J	12,368	8,335	44	....	518	1,503	1,273	64	92	539
A-105-J	....	....	....	....	....	....	....	....	....	....
A-106-J	13,784	7,597	22	23	577	1,980	1,149	112	74	2,250
A-107-R	13,823	8,323	27	32	574	3,298	308	70	88	1,102
A-108-R	14,786	10,150	16	49	487	2,278	87	208	302	1,210
A-109-R	14,990	9,696	29	39	509	2,220	140	529	260	1,568
A-110-R	13,824	8,365	31	....	560	2,587	261	55	66	1,899
A-111-R	....	....	....	....	....	....	....	....	....	....
A-112-R	13,487	8,104	42	29	560	2,537	231	72	149	1,761

HEAT BALANCE—PERCENTAGES

TESTS SERIES A

Table 19

Designation of Test	Per cent. of Heat of Fuel Fired								
	Absorbed by Boiler	To Moisture in Coal	To Moisture in Air	To Hydrogen in Coal	To Escaping Gases	To Incomplete Combustion	To Combustible in Stack Cinders	To Combustible in Ash	To Radiation and Unaccounted For
1	117	118	119	120	121	122	123	124	125
A- 1-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 2-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 3-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 4-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 5-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 6-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 7-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 8-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
A- 9-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
A-101-J	71.6	0.3	.....	3.3	15.2	2.2	0.9	2.9	3.6
A-102-J	62.0	0.2	0.2	4.1	17.7	3.0	0.4	0.7	11.7
A-103-J	65.8	0.3	0.4	3.5	26.9	0.8	3.7	2.8	-4.2
A-104-J	67.4	0.4	.....	4.2	12.2	10.3	0.5	0.7	4.3
A-105-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
A-106-J	55.1	0.2	0.2	4.2	14.4	8.3	0.8	0.5	16.3
A-107-R	60.2	0.2	0.2	4.2	23.9	2.2	0.5	0.6	8.0
A-108-R	68.7	0.1	0.3	3.3	15.4	0.6	1.4	2.0	8.2
A-109-R	64.7	0.2	0.3	3.4	14.8	0.9	3.5	1.7	10.5
A-110-R	60.5	0.2	.....	4.1	18.7	1.9	0.4	0.5	13.7
A-111-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
A-112-R	60.1	0.3	0.2	4.2	18.8	1.7	0.5	1.1	13.1

GENERAL CONDITIONS

TESTS SERIES B

Table 20

DESIGNATION OF TEST	DATE OF TEST	DURATION OF TEST hrs.	POWER	FURNACE	BAROMETRIC PRESSURE lbs. per sq.in.	BOIL'R PRESSURE lbs. per sq.in.	TEMPERATURE, DEGREES FAHR. — LABORATORY — BY DRY BULB THERMOMETER	TEMPERATURE, DEGREES FAHR. — LABORATORY — BY WET BULB THERMOMETER	TEMPERATURE, DEGREES FAHR. — SMOKE BOX GASES	DRAFT — BACK OF DIA-PHR'M ins. of water	DRAFT — FRONT OF DIA-PHR'M ins. of water
1	2	3	4	5	6	7	8	9	11	12	13
B-201-J	5- 6-12	7.00	Low	Without Arch	14.6	215.8	71.5	66.7	497	0.8	1.6
B-202-J	5- 3-12	3.33	Medium	Without Arch	14.7	210.9	74.3	63.7	601	2.9	7.8
B-203-J	5- 7-12	1.33	High	Without Arch	14.5	171.3	61.1	59.0	625	5.0	13.6
B-204-J	5-13-12	1.00	High	Without Arch	14.5	142.0	69.7	63.7	632	6.2	15.9
B-205-J	5-11-12	1.00	High	Without Arch	14.6	161.9	67.1	56.6	662	6.8	16.5
B-206-R	5-27-12	7.00	Low	Without Arch	14.6	212.9	80.2	67.3	558	0.8	1.3
B-207-R	5-28-12	3.33	Medium	Without Arch	14.5	207.5	77.2	69.4	622	3.2	7.4
B-208-R	5-28-12	1.00	High	Without Arch	14.5	176.3	84.5	72.9	620	5.5	13.1
B-209-R	5-29-12	0.67	High	Without Arch	14.5	182.0	77.1	72.4	647	5.4	11.3
B-301-J	5- 7-12	1.00	High	Without Arch	14.5	180.7	61.4	59.5	632	6.8	18.1
B-302-R	5-29-12	1.00	High	Without Arch	14.5	182.3	74.2	69.9	662	5.7	11.5
B-401-J	5-20-12	7.00	Low	With Arch	14.6	217.0	84.1	71.4	525	1.0	1.9
B-402-J	5-21-12	3.33	Medium	With Arch	14.6	212.7	77.4	64.9	589	3.9	8.7
B-403-J	5-22-12	1.00	High	With Arch	14.7	154.9	62.9	59.0	686	6.9	15.8
B-404-J	5-22-12	1.00	High	With Arch	14.7	157.0	69.0	62.4	704	8.7	18 8
B-405-R	6- 4-12	7.00	Low	With Arch	14.5	210.8	80.2	68.9	524	0.9	1.6
B-406-R	6- 3-12	3.33	Medium	With Arch	14.7	205.1	77.0	65.9	630	3.7	7 5
B-407-R	6- 3-12	1.00	High	With Arch	14.7	171.6	81.6	68.0	677	6.7	12.8
B-501-J	5-23-12	1.00	High	With Arch	14.7	168.6	61.3	58.8	730	9.3	22.9

FUEL

TESTS SERIES B

Table 21

DESIGNATION OF TEST	KIND OF COAL	Coal as Fired			Moisture Free Coal		
		TOTAL pounds	PER HOUR pounds	PER SQ. FT. OF GRATE PER HOUR pounds	TOTAL pounds	PER HOUR pounds	PER SQ. FT. OF GRATE PER HOUR pounds
1	16	17	18	19	20	21	22
B-201-J	Scalp Level	10,092	1,442	25.38	9,720	1,389	24.45
B-202-J	Scalp Level	11,699	3,510	61.78	11,396	3,419	60.18
B-203-J	Scalp Level	6,163	4,623	81.38	5,954	4,467	78.63
B-204-J	Scalp Level*	6,098	6,098	107.34	5,930	5,930	104.38
B-205-J	Scalp Level*	6,471	6,471	113.91	6,314	6,314	111.14
B-206-R	Scalp Level	9,168	1,310	22.52	8,971	1,282	22.04
B-207-R	Scalp Level	10,518	3,155	54.25	10,171	3,051	52.46
B-208-R	Scalp Level*	5,508	5,508	94.70	5,397	5,397	92.80
B-209-R	Scalp Level*	3,672	5,508	94.70	3,618	5,427	93.31
B-301-J	Dundon	6,822	6,822	120.08	6,631	6,631	116.72
B-302-R	Dundon	5,611	5,611	96.47	5,484	5,484	94.29
B-401-J	Scalp Level	9,929	1,418	24.96	9,571	1,367	24.06
B-402-J	Scalp Level	10,096	3,029	53.32	9,521	2,856	50.27
B-403-J	Scalp Level*	5,593	5,593	98.45	5,386	5,386	94.81
B-404-J	Scalp Level*	6,032	6,032	106.18	5,887	5,887	103.63
B-405-R	Scalp Level	9,571	1,367	23.50	9,248	1,321	22.71
B-406-R	Scalp Level†	10,133	3,040	52.27	9,752	2,926	50.31
B-407-R	Scalp Level*	5,172	5,172	88.93	5,069	5,069	87.16
B-501-J	Dundon	6,782	6,782	119.38	6,553	6,553	115.35

* Hand-picked. † Screened.

FUEL (Continued)

TESTS SERIES B

Table 22

DESIGNATION OF TEST	ASH TOTAL pounds	STACK CINDERS TOTAL pounds	MOISTURE AND ASH FREE COAL FIRED		MOISTURE AND ASH FREE COAL CONSUMED		PER CENT. OF ASH IN TERMS OF MOISTURE FREE COAL	PER CENT. OF STACK CINDERS IN TERMS OF MOISTURE FREE COAL
			TOTAL pounds	PER HOUR pounds	TOTAL pounds	PER HOUR pounds		
1	23	24	25	26	27	28	29	30
B–201–J	1,029	151	9,207	1,315	8,297	1,185	10.6	1.6
B–202–J	745	806	10,691	3,208	9,473	2,842	6.5	7.1
B–203–J	219	401	5,679	4,259	5,181	3,889	3.7	6.7
B–204–J	183	507	5,499	5,499	4,930	4,930	3.1	8.5
B–205–J	146	505	5,948	5,948	5,417	5,417	2.3	8.0
B–206–R	364	108	8,467	1,210	8,158	1,165	4.1	1.2
B–207–R	453	320	9,661	2,898	9,059	2,717	4.5	3.1
B–208–R	143	219	5,072	5,072	4,805	4,805	2.7	4.1
B–209–R	109	72	3,373	5,065	3,240	4,865	3.0	2.0
B–301–J	161	111	5,803	5,803	5,662	5,662	2.4	1.7
B–302–R	138	47	4,819	4,819	4,737	4,737	2.5	0.9
B–401–J	579	130	9,134	1,305	8,666	1,238	6.0	1.4
B–402–J	370	535	9,038	2,712	8,354	2,505	3.9	5.6
B–403–J	147	278	5,004	5,004	4,647	4,647	2.7	5.2
B–404–J	61	288	5,551	5,551	5,247	5,247	1.0	4.9
B–405–R	559	73	8,776	1,254	8,317	1,188	6.0	0.8
B–406–R	401	356	9,160	2,748	8,566	2,570	4.1	3.7
B–407–R	151	221	4,715	4,715	4,445	4,445	3.0	4.4
B–501–J	174	120	5,689	5,689	5,548	5,548	2.7	1.8

BOILER PERFORMANCE

TESTS SERIES B

Table 23

DESIGNATION OF TEST	TEMPERATURE OF FEED WATER degrees Fahr.	WATER FED TO BOILER CORRECTED pounds	QUALITY OF STEAM	FACTOR OF EVAPORATION	EQUIVALENT EVAPORATION TOTAL pounds	EQUIVALENT EVAPORATION PER HOUR pounds	EQUIVALENT EVAPORATION PER SQ. FT. OF HEATING SURFACE PER HOUR pounds
1	35	36	45	46	51	54	58
B-201-J	64.4	89,172	0.9970	1.2005	107,049	15,293	5.08
B-202-J	66.3	91,206	1.0000	1.2010	109,538	32,861	10.92
B-203-J	65.9	44,446	0.9999	1.1989	53,285	39,964	13.28
B-204-J	68.9	38,592	1.0002	1.1931	46,045	46,045	15.31
B-205-J	66.9	40,147	1.0005	1.1974	48,070	48,070	15.98
B-206-R	73.8	87,788	0.9980	1 1922	104,662	14,952	5.01
B-207-R	73.1	81,366	0.9982	1.1924	97,025	29,108	9.75
B-208-R	77.3	37,629	0.9987	1.1868	44,658	44,658	14.97
B-209-R	74.8	23,787	0.9982	1.1886	28,269	42,404	14.21
B-301-J	66.0	42,220	0.9999	1.1989	50,617	50,617	16.83
B-302-R	76.8	37,420	0.9979	1.1861	44,383	44,383	14.87
B-401-J	70.7	91,752	0.9995	1.1965	109,783	15,683	5.21
B-402-J	71.9	84,986	0.9996	1.1956	101,613	30,484	10.13
B-403-J	72.1	38,353	1.0007	1.1916	45,701	45,701	15.19
B-404-J	71.4	43,444	0.9993	1.1914	51,759	51,759	17.21
B-405-R	78.1	91,106	0.9980	1.1872	108,162	15,452	5.18
B-406-R	77.4	84,098	0.9980	1.1872	99,843	29,953	10.04
B-407-R	80.6	37,917	0.9980	1.1812	44,788	44,788	15.01
B-501-J	68.3	48,164	0 9990	1.1952	57,564	57,564	19.13

BOILER PERFORMANCE (Continued)

TESTS SERIES B

Table 24

DESIGNATION OF TEST	BOILER HORSE-POWER DEVEL-OPED	RATIO OF HEATING SURFACE TO BOILER HORSE-POWER DEVEL-OPED	EQUIVALENT EVAPORATION			B. T. U. ABSORBED BY THE BOILER		EFFICIENCY	
			PER POUND OF COAL AS FIRED pounds	PER POUND OF MOIS-TURE FREE COAL FIRED pounds	PER POUND OF MOIS-TURE AND ASH FREE COAL CON-SUMED pounds	PER POUND OF MOIS-TURE FREE COAL FIRED	PER POUND OF MOIS-TURE FREE COAL CON-SUMED	[OVER ALL] PER CENT. OF B.T.U. ABSORBED BY THE BOILER PER POUND OF FUEL FIRED	[BOILER AND FUR-NACE EX-CLUDING GRATE] PER CENT. OF B.T.U. ABSORBED BY THE BOILER PER POUND OF FUEL CON-SUMED
1	59	62	63	64	65	67	68	69	70
B-201-J	443	6.8	10.61	11.01	12.90	10,687	11,860	71.86	79.75
B-202-J	953	3.2	9.36	9.61	11.56	9,327	10,526	63.37	71.51
B-203-J	1,158	2.6	8.65	8.95	10.29	8,684	9,528	58.29	63.96
B-204-J	1,335	2.3	7.55	7.77	9.34	7,535	8,405	52.23	58.26
B-205-J	1,393	2.2	7.43	7.61	8.87	7,388	8,112	50.41	55.36
B-206-R	433	6.9	11.42	11.68	12.82	11,315	11,740	76.62	79.37
B-207-R	844	3.5	9.23	9.54	10.71	9,257	9,874	62.26	66.41
B-208-R	1,294	2.3	8.11	8.28	9.29	8,030	8,476	54.64	57.67
B-209-R	1,229	2.4	7.70	7.81	8.73	7,582	7,893	52.25	54.39
B-301-J	1,467	2.1	7.42	7.63	8.94	7,407	7,593	56.54	57.96
B-302-R	1,287	2.3	7.91	8.09	9.37	7,853	7,990	59.23	60.26
B-401-J	455	6.6	11.06	11.47	12.67	11,130	11,731	74.82	78.85
B-402-J	884	3.4	10.07	10.67	12.16	10,357	11,205	69.79	75.50
B-403-J	1,325	2.3	8.17	8.49	9.84	8,234	8,866	56.76	61.12
B-404-J	1,500	2.0	8.58	8.79	9.86	8,532	9,028	57.90	61.27
B-405-R	448	6.7	11.30	11.70	13.01	11,350	11,976	76.50	80.72
B-406-R	868	3.4	9.85	10.24	11.66	9,935	10,625	67.42	72.10
B-407-R	1,298	2.3	8.66	8.84	10.08	8,574	9,094	58.87	62.43
B-501-J	1,669	1.8	8.49	8.78	10.38	8,524	8,741	65.34	67.01

SMOKE BOX GASES AND AIR SUPPLY

TESTS SERIES B

Table 25

DESIGNATION OF TEST	GAS ANALYSIS PER CENT. BY VOLUME				DRY GAS PER POUND		AIR PER POUND		RATIO OF AIR SUPPLIED TO THEORETICAL REQUIREMENT
	CO_2	O_2	CO	N	CARBON CONSUMED pounds	MOISTURE FREE COAL FIRED pounds	CARBON CONSUMED pounds	MOISTURE FREE COAL FIRED pounds	
1	71	72	73	74	75	76	77	78	79
B-201-J	11.0	8.1	0.1	80.8	22.6	19.4	22.1	19.0	1.6
B-202-J	9.8	9.2	0.0	81.0	25.5	21.6	25.1	21.3	1.7
B-203-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-204-J	7.0	12.8	0.0	80.2	35.3	29.6	34.7	29.1	2.5
B-205-J	6.4	12.6	0.0	81.0	38.5	32.7	38.4	32.7	2.4
B-206-R	10.8	7.8	0.1	81.3	23.0	19.6	22.6	19.8	1.6
B-207-R	8.8	10.6	0.0	80.6	28.3	24.3	27.8	23.9	2.0
B-208-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-209-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-301-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-302-R	9.4	9.8	0.3	80.5	25.7	19.2	25.2	18.8	1.8
B-401-J	9.6	9.7	0.1	80.6	25.7	22.3	25.2	21.8	1.8
B-402-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-403-J	7.3	11.1	0.1	81.5	33.3	27.9	33.4	27.9	2.1
B-404-J	8.1	10.3	0.0	81.6	30.6	26.0	30.6	26.0	1.9
B-405-R	10.4	8.8	0.0	80.8	24.1	20.7	23.6	20.2	1.7
B-406-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-407-R	5.6	14.7	0.0	79.7	43.9	37.0	43.1	36.4	3.3
B-501-J	10.2	7.8	0.1	81.9	24.2	17.9	24.1	17.8	1.6

CHEMICAL ANALYSIS—COAL

TESTS SERIES B

Table 26

DESIGNATION OF TEST	PROXIMATE ANALYSIS COAL AS FIRED				ULTIMATE ANALYSIS MOISTURE FREE COAL					
	MOISTURE per cent.	VOLATILE MATTER per cent.	FIXED CARBON per cent.	ASH per cent.	HYDROGEN per cent.	CARBON per cent.	NITROGEN per cent.	OXYGEN per cent.	SULPHUR per cent.	ASH per cent.
1	80	81	82	83	84	85	86	87	88	89
B-201-J	3.69	16.09	75.14	5.08	4.34	85.89	1.33	2.30	0.86	5.28
B-202-J	2.59	16.46	74.92	6.03	4.28	84.85	1.32	2.27	1.09	6.19
B-203-J	3.39	16.54	75.60	4.47	4.36	86.34	1.34	2.31	1.03	4.62
B-204-J	2.75	17.10	73.08	7.07	4.24	83.91	1.30	2.25	1.03	7.27
B-205-J	2.43	16.79	75.13	5.65	4.30	85.16	1.32	2.28	1.14	5.80
B-206-R	2.15	16.45	75.90	5.50	4.31	85.38	1.32	2.28	1.09	5.62
B-207-R	3.30	17.56	74.30	4.84	4.34	86.08	1.34	2.30	0.95	5.01
B-208-R	2.01	16.76	75.33	5.90	4.30	85.21	1.32	2.28	0.87	6.02
B-209-R	1.48	17.17	74.67	6.68	4.26	84.41	1.31	2.26	0.98	6.78
B-301-J	2.80	32.10	52.97	12.13	4.64	74.42	1.47	6.17	0.82	12.48
B-302-R	2.27	33.75	52.14	11.84	4.66	74.79	1.47	6.20	0.76	12.12
B-401-J	3.61	16.55	75.44	4.40	4.37	86.57	1.34	2.32	0.83	4.57
B-402-J	5.70	16.50	73.02	4.78	4.35	86.12	1.34	2.31	0.81	5.07
B-403-J	3.70	16.41	73.05	6.84	4.22	83.66	1.30	2.24	1.48	7.10
B-404-J	2.40	17.38	74.66	5.56	4.29	84.99	1.32	2.27	1.43	5.70
B-405-R	3.37	18.10	73.60	4.93	4.34	85.89	1.33	2.30	1.04	5.10
B-406-R	3.76	16.51	73.89	5.84	4.29	84.90	1.32	2.27	1.15	6.07
B-407-R	1.99	17.18	73.98	6.85	4.26	84.37	1.31	2.26	0.81	6.99
B-501-J	3.38	34.34	49.54	12.74	4.60	73.84	1.45	6.13	0.80	13.18

CHEMICAL ANALYSIS—STACK CINDERS—ASH

TESTS SERIES B

Table 27

DESIGNATION OF TEST	Proximate Analysis—Stack Cinders				Proximate Analysis—Ash			
	MOISTURE per cent.	VOLATILE MATTER per cent.	FIXED CARBON per cent.	ASH per cent.	MOISTURE per cent.	VOLATILE MATTER per cent.	FIXED CARBON per cent.	ASH per cent.
1	90	91	92	93	94	95	96	97
B-201-J	1.05	6.13	63.30	29.52	0.82	5.42	72.95	20.81
B-202-J	0.51	2.52	81.76	15.21	1.13	6.67	65.82	26.38
B-203-J	0.43	2.47	84.23	12.87	0.65	6.61	61.90	30.84
B-204-J	0.21	2.35	85.85	11.59	0.66	7.11	59.60	32.63
B-205-J	0.16	1.96	86.96	10.92	3.91	8.88	47.46	39.75
B-206-R	3.55	6.24	58.65	31.56	2.77	6.29	59.39	31.55
B-207-R	0.38	3.48	78.29	17.85	1.54	5.93	69.21	23.32
B-208-R	0.22	2.80	84.18	12.80	0.17	4.57	48.60	46.66
B-209-R	0.21	2.95	83.72	13.12	0.68	5.87	59.48	33.97
B-301-J	0.15	4.43	74.05	21.37	0.83	3.37	29.85	65.95
B-302-R	0.00	3.74	77.57	18.69	1.05	4.16	27.97	66.82
B-401-J	0.93	5.37	62.24	31.46	0.51	9.35	56.21	33.93
B-402-J	0.53	2.56	79.06	17.85	2.36	7.33	59.41	30.90
B-403-J	0.28	2.36	87.47	9.89	0.75	6.46	67.28	25.51
B-404-J	0.28	2.48	89.62	7.62	0.36	4.21	59.37	36.06
B-405-R	0.00	5.04	56.91	38.05	0.34	8.20	65.82	25.64
B-406-R	0.00	2.65	84.65	12.70	0.65	7.31	63.35	28.69
B-407-R	0.10	2.51	82.87	14.52	0.00	6.52	47.30	46.18
B-501-J	0.24	3.66	76.22	19.88	3.38	3.24	22.67	70.71

CALORIFIC VALUES

TESTS SERIES B

Table 28

DESIGNATION OF TEST	PER CENT. OF COMBUSTIBLE IN STACK CINDERS	PER CENT. OF COMBUSTIBLE IN ASH	CALORIFIC VALUE BY OXYGEN CALORIMETER				CALORIFIC VALUE PER POUND OF ASH [ESTIMATED] B. T. U.
			PER POUND OF COAL AS FIRED B. T. U.	PER POUND OF MOISTURE FREE COAL B. T. U.	PER POUND OF MOISTURE AND ASH FREE COAL B. T. U.	PER POUND OF STACK CINDERS B. T. U.	
1	99	100	102	103	104	105	106
B-201-J	69.43	78.37	14,325	14,872	15,700	9,884	11,219
B-202-J	84.28	72.49	14,338	14,719	15,691	12,040	10,371
B-203-J	86.70	68.51	14,392	14,897	15,619	12,386	9,756
B-204-J	88.20	66.71	14,031	14,427	15,557	12,604	9,463
B-205-J	88.92	56.34	14,297	14,654	15,556	12,647	7,991
B-206-R	64.89	65.68	14,740	14,792	15,673	9,211	9,386
B-207-R	81.77	75.14	14,377	14,868	15,651	11,657	10,725
B-208-R	86.98	53.17	14,402	14,697	15,638	12,397	7,582
B-209-R	86.67	65.35	14,298	14,512	15,566	12,330	9,275
B-301-J	78.48	33.22	12,733	13,100	14,969	11,176	4,697
B-302-R	81.31	32.13	12,958	13,259	15,088	11,594	4,579
B-401-J	67.61	65.56	14,340	14,877	15,590	9,652	9,320
B-402-J	81.62	66.74	13,996	14,841	15,633	11,648	9,513
B-403-J	89.83	73.74	13,970	14,506	15,615	12,746	10,500
B-404-J	92.10	63.58	14,381	14,735	15,624	13,055	9,058
B-405-R	61.95	74.02	14,337	14,837	15,635	8,867	10,552
B-406-R	87.30	70.66	14,183	14,737	15,689	12,469	10,108
B-407-R	85.38	53.82	14,276	14,566	15,662	12,195	7,686
B-501-J	79.88	25.91	12,604	13,045	15,025	11,376	3,677

HEAT BALANCE—BRITISH THERMAL UNITS

TESTS SERIES B

Table 29

DESIGNATION OF TEST	B. T. U. PER POUND OF MOISTURE FREE COAL	B. T. U. ABSORBED BY BOILER PER POUND OF MOISTURE FREE COAL	B. T. U. LOSS PER POUND OF MOISTURE FREE COAL FIRED							
			DUE TO MOISTURE IN COAL	DUE TO MOISTURE IN AIR	DUE TO HYDROGEN IN COAL	DUE TO ESCAPING GASES	DUE TO INCOMPLETE COMBUSTION	DUE TO COMBUSTIBLE IN STACK CINDERS	DUE TO COMBUSTIBLE IN ASH	DUE TO RADIATION AND UNACCOUNTED FOR
1	107	108	109	110	111	112	113	114	115	116
B-201-J	14,872	10,687	48	49	486	1,979	78	153	1,187	205
B-202-J	14,719	9,327	34	53	497	2,731	0	851	679	547
B-203-J	....	....	....	....	....	....	....	....	....	....
B-204-J	14,427	7,535	37	114	500	3,992	0	1,078	291	881
B-205-J	14,654	7,388	33	64	514	4,675	0	1,012	185	783
B-206-R	14,792	11,315	28	49	491	2,244	79	111	381	95
B-207-R	14,868	9,257	44	86	507	3,180	0	367	477	950
B-208-R	....	....	....	....	....	....	....	....	....	....
B-209-R	....	....	....	....	....	....	....	....	....	....
B-301-J	....	....	....	....	....	....	....	....	....	....
B-302-R	13,259	7,853	31	78	554	2,711	235	99	115	1,584
B-401-J	14,877	11,130	47	63	490	2,356	88	131	564	8
B-402-J	....	....	....	....	....	....	....	....	....	....
B-403-J	14,506	8,234	52	82	510	4,170	119	657	287	395
B-404-J	14,735	8,532	31	77	480	3,958	0	639	94	924
B-405-R	14,837	11,350	44	55	488	2,202	0	70	637	-8
B-406-R	....	....	....	....	....	....	....	....	....	....
B-407-R	14,566	8,574	27	112	506	5,286	0	531	229	-428
B-501-J	13,045	8,524	48	56	565	2,872	75	208	98	600

HEAT BALANCE—PERCENTAGES

TESTS SERIES B

Table 30

DESIGNATION OF TEST	PER CENT. OF HEAT OF FUEL FIRED								
	ABSORBED BY BOILER	TO MOISTURE IN COAL	TO MOISTURE IN AIR	TO HYDROGEN IN COAL	TO ESCAPING GASES	TO INCOMPLETE COMBUSTION	TO COMBUSTIBLE IN STACK CINDERS	TO COMBUSTIBLE IN ASH	TO RADIATION AND UNACCOUNTED FOR
1	117	118	119	120	121	122	123	124	125
B-201-J	71.9	0.3	0.3	3.3	13.3	0.5	1.0	8.0	1.4
B-202-J	63.4	0.2	0.4	3.4	18.6	0.0	5.8	4.6	3.6
B-203-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-204-J	52.2	0.3	0.8	3.5	27.7	0.0	7.5	2.0	6.0
B-205-J	50.4	0.2	0.4	3.5	31.9	0.0	6.9	1.3	5.4
B-206-R	76.5	0.2	0.3	3.3	15.2	0.5	0.8	2.6	0.6
B-207-R	62.3	0.3	0.6	3.4	21.4	0.0	2.5	0.3	6.3
B-208-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-209-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-301-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-302-R	59.2	0.2	0.6	4.2	20.4	1.8	0.7	0.9	12.0
B-401-J	74.8	0.3	0.4	3.3	15.8	0.6	0.9	3.8	0.1
B-402-J	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-403-J	56.8	0.4	0.6	3.5	28.7	0.8	4.5	2.0	2.7
B-404-J	57.9	0.2	0.5	3.3	26.9	0.0	4.3	0.6	6.3
B-405-R	76.5	0.3	0.4	3.3	14.8	0.0	0.5	4.3	-0.1
B-406-R	.....	.....	.....	.....	.....	.....	.....	.....	.....
B-407-R	58.9	0.2	0.8	3.5	36.3	0.0	3.6	1.6	-4.9
B-501-J	65.3	0.4	0.4	4.3	22.0	0.6	1.6	0.8	4.6

XIV. A Summary

142. *A Brief Story of the Development of the Locomotive Boiler* (Chapter III) emphasizes two facts, (1) that the design of such boilers has from the beginning been subject to frequent change, and (2) that the difficulties in the construction and maintenance of such boilers have always centered in the firebox.

143. *The Radial-Stay Boiler* (Chapter IV) is recognized as the most important detail of the modern high-power locomotive. Many embellishments in its construction have from time to time been introduced, and present-day designs represent a highly developed practice. But forces are always present within the structure of the radial-stay boiler which make its maintenance difficult and which ultimately bring about its ruin. Like all its predecessors, the radial-stay boiler is weak under low-water conditions and failures, sometimes disastrous, are not uncommon. No one who considers the progress of the past can assume for a moment that our present-day practice is final. The radial-stay boiler has had its predecessors and they have disappeared, and no one can doubt that the radial-stay boiler itself is but an embryo predecessor of a type which must soon be revealed.

144. *The Jacobs-Shupert Boiler* (Chapter V) seeks to overcome some of the defects of the radial-stay type. Its firebox construction is more than a modification of preëxisting forms; it is new in its contour, in the means employed for its support, and in the fact that it is made up of a considerable number of comparatively small plates. The contour of the Jacobs-Shupert firebox is not dissimilar to that of the corrugated furnaces so long and so generally used in marine service. It has no radial stays and there are no stay-bolts except in the tube-sheet and door-sheet. There are no rivets or stay-heads on the fire side of the crown-sheet or side-sheets. The rivets joining the several sections making up the firebox structure are not inside of the firebox. They can not be seen from the firebox and they can not be affected by the direct action of the heat from the firebox. They are above the crown in the water space of the boiler at a distance sufficiently far from the heating-surface of the firebox to be undisturbed by any condition that may arise within the firebox. These features place the design of the Jacobs-Shupert boiler upon a plane which, from a purely mechanical point of view, is essentially higher than that which is occupied by the normal radial-stay boiler. The fact also that in the manufacture of these boilers, the principle of interchangeability is employed, establishes a high standard of workmanship. Interchangeability in construction operates to improve quality and to reduce costs. In the manufacture of the Jacobs-Shupert firebox, machinery is used instead of men. Each operation is simple and yet the result is precise. There is no drifting of holes and no

local heating of plates which have been set in place in the boiler. The result of the new process is a boiler accurately made, substantially put together, and comparatively free from initial strains. The design and the methods of manufacture combined permit repair parts to be carried, and provide an inexpensive procedure in maintenance.

145. *The Jacobs-Shupert Boiler in Service* (Chapter VI) was made the subject of an inspection at several division points, and on the road along the line of the Santa Fe, where at the time of the inspection (November, 1911) a hundred and sixty-nine locomotives were in service. As a result of five days' inspection, conclusions were reached as follows:

1. The construction of the Jacobs-Shupert firebox admits of easy and thorough inspection.
2. The Jacobs-Shupert firebox gives no trouble by leaking at the mud-ring. Not a single case of a leaky mud-ring could be found.
3. The fireboxes give no trouble by leaking between sections.
4. No indication could be found of grooving or cracking at the fillet or in any other part of the sections making up the firebox.
5. The fireboxes examined, while very large, appear to resist perfectly the pressure imposed, which in all cases was above 200 pounds.
6. The firebox structure of a Jacobs-Shupert boiler after a year of service in a district of alkali water, appeared as though new, while that of a radial-stay boiler in the same service for the same or a lesser length of time presented unmistakable evidences of degeneration.
7. Evidence was not lacking to prove that minor defects, such as those which may arise in a Jacobs-Shupert boiler from accumulation of scale or because of low water, are easily repaired.

Some months after this inspection, it was reported that defects had appeared in the outside wrapper-sheets of some of the older boilers. The cause was easily seen to be in a defective arrangement of some of the longitudinal stays, and the remedy was simple. The occasion for the occurrence of such defects is avoided in more recent designs.

146. *A Program of Tests* (Chapter VII) designed to disclose the performance of the Jacobs-Shupert boiler in comparison with that of a radial-stay boiler was outlined as follows:

The boilers to be tested were to be designed for locomotive service and to be identical in their general dimensions. They were to differ from each other only in the construction of the firebox and in the means employed for supporting it. One boiler was to be equipped with a Jacobs-Shupert firebox and the other with a radial-stay firebox conforming to the best present-day practice.

A laboratory was to be provided in which the two boilers could be erected and equipped with all apparatus necessary for testing. The tests specified were to be grouped into three series designated as Series A, B, and C, respectively.

Series A was planned to disclose the relative amount of heat absorbed by the fireboxes and by the tubes of the two boilers under similar conditions of operation. To facilitate these tests, it was proposed to have the boilers constructed with a partition separating the water space into two

compartments, one of which was to include the firebox surface and the other the tube surface. In carrying out the tests, these compartments were to be separately fed with weighed water. Not less than three tests, one at low power, one at medium power, and one at high power, were to be made upon each boiler. It was believed that the results would serve to establish the relative value of a unit area of firebox heating-surface as compared with that of a unit area of tube-heating-surface—facts which American engineers have long desired to know—and that they would disclose the difference, if any, in the heat-absorbing capacity of the two fireboxes tested.

Series B was to be made up of tests of normal boilers. The boilers which had served in the tests of Series A were to undergo such reconstruction as might be found necessary to the removal of the partitions. This accomplished, there would be available for the further work a normal Jacobs-Shupert boiler and a normal radial-stay boiler. Each boiler was then to be subjected to a series of evaporative tests for the purpose of establishing its evaporative efficiency and capacity under different rates of power. In addition to data usually secured in boiler testing, it was proposed to make of record such information as might be possible concerning the circulation of water within the two boilers. The purpose of this series was to secure an accurate measure of the evaporative performance of the Jacobs-Shupert boiler and of a normal radial-stay boiler.

Series C was planned to disclose the relative strength of the two boilers under low-water conditions. In preparation for the tests of this series the boilers were to be removed from the testing laboratory and set up with everything necessary to their operation in a location where their explosion would result in no harm to surrounding property. Adequate provisions were to be made for the safety of observers. The boilers were to be operated, the supply of feed-water was to be cut off or so controlled that the firebox would be uncovered, and the low-water conditions were to be continued until failure occurred.

147. *The General Dimensions of the Boilers Tested* (Chapter VII) were as follows:

	Jacobs-Shupert	Radial-stay
Type of boiler......	Ext'd wagon top	Ext'd wagon top
Diameter of shell..................	70″	70″
Number of 2¼″ tubes..............	290	290
Length of tubes....................	18′2″	18′2″
Length of firebox..................	9′1⅝″	9′1 11/16″
Width of firebox..................	6′4⅜″	6′4¼″
Total heating surface..............	3008.4	2989.3

148. *The Percentage of the Total Heat Absorbed by the Boiler, which is taken up by the Firebox* (Chapter VIII) varies with the rate of power at which the boiler is worked. It is affected also by the character of the fuel used.

When oil fuel was fired at the rate of 2,200 pounds an hour:

(*a*) The Jacobs-Shupert boiler evaporated 40,000 pounds of water per hour. Of this amount, 16,000 pounds were evaporated by the firebox and 24,000 pounds by the tubes.

(*b*) The whole boiler developed 1,200 horse-power, of which amount nearly 500 horse-power was developed by the firebox.

(*c*) The average rate of evaporation per foot of heating-surface per hour for the whole boiler was 9.78 pounds.
(*d*) The average rate of evaporation per foot of heating-surface per hour for the firebox was 49.59 pounds, and for the tubes 6.47 pounds.
(*e*) The ratio of heat absorbed per foot of heating-surface by the firebox to that absorbed per foot of tube heating-surface was as 7.6 to 1.

When oil is used as fuel, the percentage of the total heat absorbed that is taken up by the firebox can be found by dividing the pounds of oil fired per hour by 100 and subtracting the quotient from 62. Strictly speaking, the application of this statement should be limited to those rates of firing which were covered by the experiments; that is, to rates between the limits of 700 pounds and 2,200 pounds of oil per hour.

When a long-flamed bituminous (Dundon) coal was fired at the rate of 4,340 pounds per hour:

(*a*) The Jacobs-Shupert boiler evaporated 35,405 pounds of water per hour, of which amount 11,982 pounds were evaporated by the firebox and 23,423 pounds by the tubes.
(*b*) The whole boiler developed 1,026 horse-power, of which amount 304 horse-power were developed by the firebox.
(*c*) The average rate of evaporation per foot of heating-surface per hour for the whole boiler was 11.77 pounds.
(*d*) The average rate of evaporation per foot of firebox heating-surface was 51.92, and for the tube heating-surface 8.43.
(*e*) The ratio of heat absorbed per foot of firebox heating surface to that absorbed per foot of tube heating-surface was as 6.15 to 1.

When long-flamed bituminous coal is used as fuel, the percentage of the total heat absorbed that is taken up by the firebox can be found by dividing the pounds of coal fired per hour by 190 and subtracting the quotient from 56. Strictly speaking, the application of this statement should be limited to those rates of firing which were embraced by the experiments; that is, to rates ranging from 1,400 pounds to 4,500 pounds of coal per hour.

Different fuels produce different results in the distribution of heat. For example, assuming the Jacobs-Shupert boiler to be evaporating 20,000 pounds of water per hour, the percentage of the whole quantity of heat absorbed, which is taken up by the firebox, is as follows:

(*a*) When oil is used as fuel.........................42%
(*b*) When long-flame bituminous coal is used as fuel.. 42%
(*c*) When short-flame bituminous coal is used as fuel.. 35%

149. *Results of Evaporative Tests of a Normal Jacobs-Shupert Boiler and a Normal Radial-Stay Boiler* (Chapter IX) disclose the evaporative efficiency and the capacity of the two boilers tested.

The high efficiency of the Jacobs-Shupert boiler, unaided by the presence of a brick arch is to be seen in the fact that when fired with 1,315 pounds of Dundon coal per hour it:

(*a*) Evaporated 15,293 pounds of water per hour.

(*b*) Evaporated 5.08 pounds of water per square foot of heating-surface per hour.

(*c*) Evaporated 11.01 pounds of water per pound of coal.

(*d*) Developed 443 horse-power.

(*e*) Developed an overall efficiency of 71.86 per cent.

(*f*) Developed an efficiency, excluding the grate, of 79.75 per cent.

The various effects resulting from operation at higher rates of power may be set forth as follows:

Pounds of coal fired per hour	1,389	3,419	5,930	6,314
Thermal units for each pound of coal:				
(*a*) Absorbed by water in boiler.	10,687	9,327	7,532	7,388
(*b*) Lost by moisture in coal	48	34	37	33
(*c*) Lost by moisture in air	49	53	114	54
(*d*) Lost by hydrogen in coal.	486	497	500	514
(*e*) Lost by smoke-box gases	1,979	2,731	3,992	4,675
(*f*) Lost by incomplete combustion.	78			
(*g*) Lost by cinders passing up stack.	153	851	1,078	1,012
(*h*) Lost by combustion in ash.	1,187	679	291	185
(*i*) Lost by radiation and unaccounted for.	205	547	881	783
Total B. T. U. per pound of coal. . .	14,872	14,719	14,425	14,654

The evaporative efficiencies of the Jacobs-Shupert boiler and of the radial-stay boiler were found to be practically identical.

In the matter of capacity the data show the Jacobs-Shupert boiler to possess some advantages over the radial-stay boiler. The Jacobs-Shupert boiler was forced without the least sign of distress to an unprecedented rate of power. It was fired at the rate of 6,553 pounds of coal per hour resulting in:

A rate of combustion equaling 119.38 pounds of coal per foot of grate per hour.

An evaporation of 57,564 pounds of water per hour, or the equivalent of 19.13 pounds of water per foot of heating-surface per hour.

The development of 1,669 boiler horse-power, or the equivalent of one boiler horse-power for each 1.8 foot of heating-surface.

An evaporation per pound of coal, notwithstanding the high rate of power developed, of 8.78 pounds of water.

The maintenance of an overall boiler efficiency of 65.34 per cent, and of the boiler, exclusive of the grate, of 67 per cent.

The published records of boiler performance disclose no results of equal significance.

150. *The Brick Arch as a Factor in Boiler Performance* (Chapter X) is always beneficial. Its effect depends upon the characteristics of the fuel. When a short-flamed bituminous (Scalp-Level) coal was used, the addition of an arch to either boiler tested, increased the amount of water evaporated per pound of coal 0.6 of a pound; that is, assuming either boiler to be fired with 6,500 pounds of Scalp-Level coal per hour, they will evaporate 7.35 pounds of water per pound of coal without the arch, and 7.95 pounds with the arch, a gain resulting from the introduction of the arch of 8 per cent. The substitution of a long-flamed bituminous (Dundon) coal will, under similar conditions, result in the evaporation of 7.7 pounds of water per pound of coal without the arch, and 8.7 pounds with the arch, a gain resulting from the introduction of the arch of 12 per cent.

151. *Some Facts of Interest with Reference to the Circulation of Water within a Locomotive Boiler* (Chapter XII) have been developed. The motion of the water within a locomotive boiler in response to the energy transmitted to it in the form of heat is known to have an important bearing on the upkeep and life of the boiler, and there has been much speculation concerning the direction and strength of the circulating currents. It has been urged, for example, that the presence of the stay-sheets which enter into the construction of the Jacobs-Shupert boiler retard the fore-and-aft movement of water and that they are, therefore, objectionable. As the stay-sheets are provided with widely distributed openings of large area, such criticisms necessarily assume fore-and-aft currents which are tremendously vigorous. The presence of such vigorous currents has been questioned. An experimental inquiry conducted by Mr. George Fowler sustains the very rational contention that only enough water passes back from the barrel of the boiler to the water-legs of the firebox to make good that which the firebox evaporates. Since the firebox evaporates from 30 to 50 per cent of the water handled by the boiler, a similar percentage of the total feed must, in the case of the Jacobs-Shupert boiler, find its way through the ports in the forward stay-sheet. Some of this water is evaporated before the second stay-sheet is reached. With the passage of each section, the backward flow diminishes until at the last stay-sheet only enough passes to supply that which the last section evaporates.

As the stay-sheets have an aggregate port-area below the water-line of 1½ square feet and as only 30 to 50 per cent. of the total water delivered by the injectors must pass by them, it is inconceivable that their presence can affect the circulation unfavorably.

The strongest currents which are set up in a locomotive boiler are those which sweep over the heating-surface in a direction which in its general tendency is vertical. These are the most important of the circulating currents, and with respect to them, the Jacobs-Shupert boiler presents superior advantages, for the water space about a Jacobs-Shupert firebox presents broad, unobstructed vertical channels which in the matter of form and dimensions have no counterpart in the radial-stay boiler.

The conclusion as drawn from analysis and experiment, is to the effect that with reference to circulation the Jacobs-Shupert boiler is at no disadvantage as compared with the radial-stay type, but on the contrary possesses elements of distinct superiority to that type.

152. *The Superior Strength of the Jacobs-Shupert Boiler under Low-Water Conditions* (Chapter XI) has been abundantly demonstrated by experiment. In the progress of the tests each boiler in turn was put under steam. Its draft was adjusted to give an evaporation of approximately 10 pounds of water per foot of heating-surface per hour. Upon signal, the injectors were shut off and the delivery of feed-water ceased. Thereafter the water-level steadily declined, but the fire was not checked. The purpose was to maintain all the general conditions the same for both boilers, and the data show that this purpose was satisfactorily achieved.

In the test of the Jacobs-Shupert boiler, the water-level receded to the bottom of a special water-glass 25½ inches below the level of the crown-sheet in 34 minutes after it had passed the level of the crown-sheet, but there was no failure or serious leak. The extent of the submerged heating-surface continued steadily to diminish and the steam-jet from the exhaust ip which made heavy demands upon the boiler began to reduce the steam pressure, until finally when the water had fallen nearly 40 inches below the crown-sheet and the pressure had been reduced to 50 pounds, 53 minutes after the water had fallen to the level of the crown-sheet, the test was ended. The Jacobs-Shupert boiler had been boiled nearly dry and no failure had occurred. An inspection of the boiler after the test showed all the usual effects of overheating except that the firebox was intact. Three-quarters of the tubes were out of water and were sagged from the effects of the heat. Several tubes had collapsed. The crown and sides of the firebox for half their height presented the scale and color of newly heated metal. There was some change in the curvature of sections, but there were no local pocketing and no leaks between sections. The integrity of the firebox was complete, and so far as its condition was concerned, the boiler at the conclusion of the test might have been refilled and operated. Probably no other type of locomotive boiler now in common use could have withstood such a test.

The radial-stay boiler was subjected to a similar test. The conditions of operation imposed were identical with those which had prevailed during the test of the Jacobs-Shupert boiler. Seventeen and three-quarters minutes after the water in glass had fallen to the level of the crown-sheet, when its level was 14½ inches below the crown, the boiler failed. One-half the crown-sheet came down. The rear end of the boiler was lifted from its foundation and the brickwork making up the furnace construction was scattered in all directions over a radius of 150 feet. An examination of the boiler showed only the upper row of tubes to have been out of water, and these had not been heated sufficiently to make them sag. The lowering of the water-level had not been sufficient to allow the side-

sheets or the back sheet or the tube-sheet to take on evidences of overheating, facts which suggest the brevity of the interval during which the crown was actually exposed, and yet in the interval, the crown of a new boiler came down with explosive effect. The failure was complete; the boiler had broken away from all its fastenings, property in its vicinity was disturbed, and the boiler itself left incapable of rendering further immediate service.

A comparison of these statements shows conclusively the superior strength and safety under low-water conditions of the Jacobs-Shupert boiler.

153. *The General Conclusions* justified by the work are to the effect that the design of the Jacobs-Shupert boiler is the result of a carefully studied development of preëxisting practice; that the design easily admits of a grade of workmanship difficult to attain in the construction of preexisting types of locomotive boilers; that those features which are peculiar to the new construction are such as tend to reduce cost in maintenance; that the evaporative efficiency of the Jacobs-Shupert boiler is the same as that of a radial-stay boiler of the same dimensions; that the steaming capacity of the Jacobs-Shupert boiler is, in general, the same as that of a radial-stay boiler, but that it may be forced without danger of injury to higher power; that the Jacobs-Shupert boiler presents nothing in its internal construction which can interfere with the usual movement of water over the heating-surfaces, and that in the matter of circulation it possesses some advantage when compared with other types of locomotive boilers; that the superior strength of the Jacobs-Shupert boiler under low-water conditions permits it to endure overheating without failure for long periods of time, where the normal radial-stay boiler quickly fails; and that where the overheating is so severe that it can not be resisted, the result will be a blow-out and not a disastrous explosion.

Wm F. M. Goss.